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...THING CAPACITY AND GRIP STRENGTH OF PRESCHOOL CHILDREN

By

Eleanor Metheny

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BREATHING CAPACITY AND GRIP STRENGTH OF PRESCHOOL CHILDREN

by

ELEANOR METHENY

GEORGE D. STODDARD, PH.D., EDITOR

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FOREWORD

Dr. Metheny's study of breathing capacity and grip strength constitutes a real advance in this field. In the first place, there are presented new designs for the spirometer and the dynamometer, designs which permit high reliability in the measurement of preschool children. These new instruments are the work of Mr. J. G. Sentinella.

Data on breathing capacity and grip strength are presented for 169 children from ages 2½ to 6½. Over 6,000 tests of each function are utilized and their relation to other anthropometric measures is analyzed. In both breathing capacity and grip strength boys tend to be slightly superior to girls. For this sampling of children, which is a selected one in terms of social status and mental ability, there is no relationship between the functions measured and intelligence.

There has long been an interest in the possible relation of breathing capacity and grip strength to health and physical condition. While a general prediction of health is not indicated from Dr. Metheny's data, there is some evidence of a decrease in strength and breathing capacity prior to the onset of a cold. In view of its important practical implications, this question warrants further investigation.

It may be said that Dr. Metheny's whole study, involving as it does improved instruments, new anthropometric measurements and refined methods of statistical analysis, should serve well as a starting point for further substantial research.

George D. Stoddard

Office of the Director
Iowa Child Welfare Research Station
University of Iowa
October 14, 1940

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Section I

PROBLEM AND DATA

CHAPTER I

INTRODUCTION TO THE PROBLEM

When in 1846 John Hutchinson (64) built an apparatus which he named the spirometer and began to measure the amount of air an individual could exhale after a full inspiration, he opened up a subject that has since captured the interest of numerous investigators. Hutchinson called this measure the "vital capacity" of the individual in the belief that it was an index of the "soundness of the lungs" or their ability to supply the tissues of the body with air, a vital necessity. Later investigators sometimes used the term "lung capacity," which is a misnomer, since after even the most forcible exhalation those portions of the contents of the lungs known as the residual air and the minimal air still remain. More recently the term "breathing capacity" has been suggested as being more precisely descriptive of the measure. In the research literature the terms have often been used interchangeably. In this report the term breathing capacity will be used consistently except in direct quotations from the literature.

Interest in breathing capacity and investigations concerning it have centered principally about its effectiveness: (1) as a measure of physical and physiological growth; (2) as an indication of the general health status of the individual; and (3) as a clinical instrument for the diagnosis and prognosis of certain specific disease conditions. In each area evidence has been adduced concerning the usefulness and significance of the test.

The scientific use of grip strength testing in this country dates back to 1873 when Sargent (22) introduced it as one item of a battery of tests intended to measure the muscular strength of Yale University students. Since that time the test has been studied: (1) as a measure of strength; (2) as a measure of physical or physiological growth; (3) as a factor in motor ability; (4) as related to hand dominance; and (5) as an indicator of the "physical fitness" of the individual. The usefulness of the test as a measure of strength and of physical or physiological growth has not been questioned, but opinion has been divided as to its significance in the other three areas.

Both grip strength and breathing capacity tests have been used extensively with children of elementary and secondary school age, with college students, and with adults. Few investigators have attempted to extend their studies to include children below six years of age. This may be attributed in part to two reasons: (1) the fact that the available instruments are too large and heavy for use with small children, and (2) the belief that children below six years of age cannot be motivated to exert maximum effort in the execution of the tests. The first of these objections can be met by modifying the instruments. The validity of the second can be determined by experimentation.

Since there is a need for tests of physical function at the preschool age level, and since research has indicated that tests of grip strength and breathing capacity serve to meet such a need for older children, it was decided to undertake an investigation of the potentialities of the two tests for preschool age children.

With this brief introduction the problem of the present investigation may be stated as follows:

1. To design a dynamometer and a spirometer suited to the size, ability, and interest of preschool children.

2. To determine whether reliable measurements of the grip strength and breathing capacity of preschool age children may be made with these instruments.

3. To standardize a procedure for administering such tests to children of preschool age.

4. To describe the development of grip strength and breathing capacity through the preschool years and to indicate the range of individual differences at each age.

5. To study the relationship of grip strength and breathing capacity to certain measures of physical and mental growth during the preschool years.

6. To provide a method for estimating the grip strength and breathing capacity of preschool children from certain measures of bodily size.

7. To investigate the relationship of grip strength and breathing capacity to certain estimates of health, both as to general status over an extended period and as to daily variations.

8. To compare the findings on preschool age children with those obtained by other investigators for older children.

CHAPTER II

THE SUBJECTS AND THE DATA

The subjects for this study were 169 white children between the ages of 2 years, 6 months and 6 years, 5 months in attendance at the preschool laboratories of the Iowa Child Welfare Research Station during the spring, summer, or fall terms of 1939. These children represent a selected group in so far as socio-economic status is concerned, as is shown by the following tabulation of fathers' occupations according to the Goodenough classification.[1]

Occupational Classification	Number	Per Cent
I	103	61
II	24	14
III	14	8
IV	3	2
V	10	6
VI		
VII		
Parents Deceased, Separated, or Not Given	15	9
	169	100

It will be seen that 75.0 per cent of the children are in classes I and II, as compared with 7.2 per cent for the general population.

The preschool laboratories include four groups of children, classified primarily on the basis of chronological age. Children in First Group are between two and three years of age, those in Second Group are between three and four years of age, those in Third Group between four and five and those in Fourth Group or Junior Primary between five and six. There was no selection of children within the preschool enrollment. All children in attendance during the time of the study were used except those in First Group during the spring term and those under 2 years, 6 months of age at the time of testing in the summer and fall terms.

[1] Florence L. Goodenough and John E. Anderson: *Experimental Child Study.* New York: Century, 1931, Pp. xiii, 546.

The data consist of 202 grip strength scores (each based on 6 days of testing with 3 trials for each hand on each day), and 206 breathing capacity scores (each based on 6 days of testing with a minimum of 5 trials on each day). Five strength test series were completed for children who failed to master the breathing capacity technique, and nine breathing capacity series were completed for children for whom no grip strength scores were available.[2]

The number of children tested at each age level was as follows:

Age	Boys	Girls
Grip Strength		
2 years, 6 months to 3 years, 5 months	21	19
3 years, 6 months to 4 years, 5 months	27	20
4 years, 6 months to 5 years, 5 months	42	28
5 years, 6 months to 6 years, 5 months	26	19
Total	116	86
Breathing Capacity		
2 years, 6 months to 3 years, 5 months	18	22
3 years, 6 months to 4 years, 5 months	31	23
4 years, 6 months to 5 years, 5 months	44	28
5 years, 6 months to 6 years, 5 months	22	18
Total	115	91

Since the grip strength and breathing capacity tests were not administered simultaneously in all cases, there is some slight shifting in the number of children in each age group from test to test. Thirty-seven children who were tested in the spring and again in the fall were used in two adjacent age groups. In all, over 7,200 grip strength and 6,000 breathing capacity tests were administered.

Additional data were secured as follows:

1. One hundred ninety-one sets of anthropometric measurements

[2] An assistant assigned to administer the tests to the twenty children in Second Group during the spring of 1939 failed to follow directions and permitted the children to take a series of small squeezes instead of requiring one sustained grip. This was not discovered until too late to retest the children during the spring term. Fortunately, eleven of these children were enrolled for the summer session, and it was possible to test them during the first week of the summer. Nine of these children could not be retested, and it was necessary to discard the strength data which had been accumulated on them.

were taken within six weeks or less of the time of the grip strength and breathing capacity tests. These measurements included:

Weight
Stature
Sitting height
Trunk length
Knee width
Elbow width
Shoulder width (bi-acromial)
Hip width (bi-iliocristal)
Chest circumference (xiphoid level)
Upper arm circumference
Forearm circumference
Thickness of skin and subcutaneous tissue
    Front of chest below left nipple
    Back of chest below left scapula
    Side of trunk above left ilium

All measurements were taken by trained observers in accordance with the techniques in use at the Iowa Child Welfare Research Station as described by McCloy (78) and Meredith (87).[3] Each child was measured independently by two observers. Those measurements which differed by amounts greater than the values established by Knott (72) were repeated by both observers. Weight was recorded in pounds and ounces and all other measurements were taken to the nearest millimeter.

2. The Stanford-Binet Intelligence Test (1937 Revision) scores for 169 children were used. These tests were given during the semester in which the grip strength and breathing capacity tests were administered.

3. Attendance records were secured for all children except those in attendance only during the summer session. These records contain notations as to the reason for, as well as the date and duration of, each absence.

4. Ratings on a five-point scale of the general health of each child were employed. These ratings were made by the preschool nurse who examined each child each day before permitting him to go to the preschool rooms. Two different nurses made the ratings, one

[3] Two of the measurements used are not described in these publications: (1) Arm length: This is defined as the length of the left arm from the acromion process (acromiale) to the tip of the longest finger (dactylion) when the arm is held at the side with the elbow, wrist, and finger joints extended. (2) Suprasternale height: This is defined as the perpendicular distance from the floor to the suprasternal notch (suprasternale) when the subject is standing erect in the position used for the measurement of stature. From this measurement, trunk length, as used in this study, is derived, being the difference between suprasternale height and leg length. Leg length is obtained by subtracting sitting height from stature.

for First, Second, and Third Groups and one for Junior Primary. These ratings were in accordance with the following directions:

> "a. In each group select the one child who is in your opinion the 'healthiest' child in the group and rate him 1. (If it is impossible to decide between two children, rate both of them 1.)
>
> "b. In each group select the one child who is in your opinion the 'least healthy' child in the group and rate him 5. (If it is impossible to decide between two children, rate both of them 5.)
>
> "c. Rate the other children in the group with reference to these two extremes, rating those who are average for the group 3, those slightly above the average 2, and those slightly below the average 4."

No attempt was made to define "health" for the two nurses who made the ratings. Both were registered nurses with wide experience in school health work with children of the ages included in this study, and were thoroughly conversant with the manifestations of health.

5. Ratings on a five-point scale of the "fatigability" of each child in First, Second, and Third Group were secured. These ratings were made independently by the head teacher and the assistant teachers in each group. The head teacher rated all children in a given group while the assistant teachers rated only those children who were directly under their supervision. These ratings were made in accordance with the following directions:

> "a. Select the one child in your group who in your opinion shows the most marked signs of fatigue by the end of the school day. Rate him 5. (If you are unable to decide between two children rate both of them 5.)
>
> "b. Select the one child in your group who in your opinion shows the fewest signs of fatigue by the end of the school day. Rate him 1. (If you are unable to decide between two children rate both of them 1.)
>
> "c. Rate the other children in your group with reference to these two extremes, rating those who are about average 3, those who show slightly less than average fatigue 2, and those who show slightly more than average fatigue 4."

Comments on the symptoms of fatigue shown by individual children were made in many cases.

6. Ratings on a five-point scale were made of the "energy ex-

penditure'' or amount of activity of each child in the Junior Primary groups. This type of rating was substituted for the ''fatigue'' rating at the request of the Junior Primary head teacher. She was of the opinion that if the day's program were properly planned five-year-old children would show no observable fatigue symptoms in the course of a half-day session. She suggested that the children be rated rather on the relative amount of energy each expended in the course of the school day. These ratings were made from 1 to 5 as described above. A rating of 1 indicated the child who engaged in the greatest amount of activity during the school day. A rating of 5 indicated the child who engaged in the least amount of activity during the school day. The intermediate ratings were 2 for slightly more than average, 3 for average, and 4 for slightly less than average.

In short, grip strength scores, breathing capacity scores, anthropometric measurements, intelligence test scores, attendance records, nurses' ratings, and preschool teachers' ratings constitute the main body of data used in this study.

A second body of data on daily variations in test scores as related to daily fluctuations in health status will be described in Section IV, Chapter XVI.

Section II

BREATHING CAPACITY

CHAPTER III

PREVIOUS STUDIES OF THE BREATHING CAPACITY OF PRESCHOOL AGE CHILDREN

This discussion is limited to studies of breathing capacity which make specific mention of the preschool ages. No attempt will be made to review the extensive body of literature dealing with the test for school children and adults. However, comment will be made on pertinent results from such studies in connection with specific phases of the present investigation.

The earliest mention found of the breathing capacity of a preschool child was made by Binet and Vaschide (20) in 1898. In discussing certain uses of the test for older children they noted that a breathing capacity of 400 c.c. (about 25 cubic inches) had been reported for a child of three years. They commented: "The child must have been very intelligent and advanced to be able to perform the test correctly!" [*Il a fallu que cet enfant fût bien intelligent et précoce pour se prêter à une expérience correcte!*] (p. 104)

During the next four years Christopher (28) and Smedley (108) in Chicago, and Hastings (57) in Nebraska, published age means for the breathing capacity of children of school age. Some four- and five-year-olds in the first grade were included by each investigator, and Smedley used a number of kindergarten children. The means reported for five-year-old children were not considered reliable by any of the men reporting them.

Similarly, Stewart (110) and Stewart and Sheets (113), in 1922, studied the breathing capacity of 2,500 children in the Minneapolis schools. Their reported means include those obtained for twenty-six boys and thirty-five girls below six years of age. Also, their tables for predicting normal breathing capacity from age and height extend downward to five years. These tables were quoted by Myers (90) and recommended by him as satisfactory norms for young children.

Schwarz, Britten, and Thompson (106), in 1928, measured the breathing capacity of 2,162 males, children and adults, in New York City. They reported means for breathing capacity for sixty chil-

dren below six years of age. Meredith (87) in 1936 reported means for breathing capacity for Iowa City boys. His subjects included sixty-four boys, five years of age.

That there is considerable disagreement among these reported means is shown by the following tabulation:

Investigator	Breathing Capacity, Cubic Inches			
	4 years		5 years	
	Number	Mean	Number	Mean
Boys				
Hastings (57)			202	41
Christopher (28)	16	44	26	57
Smedley (108)	41	45	70	57
Stewart and Sheets (113)	6	48	20	57
Schwarz, Britten and Thompson (106)	14	49	36	56
Meredith (87)			64	67
Girls				
Hastings (57)			183	35
Christopher (28)	21	49	37	55
Smedley (108)	36	46	81	52
Stewart and Sheets (113)	9	40	26	54

For school age children, Baldwin (14) reported a series of individual growth curves in breathing capacity, a few of which extend downward into the preschool years. Concerning these curves he wrote: "The individual growth curves for preschool children show significant but unexplained fluctuations at five or six years of age in . . . breathing capacity." (p. 71)

Gates (48) used a correlational approach to the relationship of certain measures of physical status, including breathing capacity, to "mental, physiological, social and emotional maturity." Fifty-eight junior primary children (average age 5.7) and fifty-seven fourth grade children (average age 9.6) were used as subjects. He found consistently low correlations for breathing capacity with various maturity ratings and mental tests and such estimates of physical status as "nutrition" (weight given in the Baldwin-Wood age-height-weight tables minus actual weight), ossified carpal area, and per cent of ossification of the carpal bones. He reported the average of his correlations for the four age-sex groups, but did not give the range.

Jersild (67) used the breathing capacity test in a study of learning and maturation of preschool children. Using twelve practice and twelve control children, five to seven years of age, he gave four initial trials for which he reported split-half reliabilities of .94

and .79. The practice group then performed the test forty-three times over an eleven-week period. At the end of the experiment both groups were tested, and very slight differences were found between them.

Wilson, Edwards, and Liss (128) discussed the use of the breathing capacity test as an aid in the diagnosis of tracheo-bronchial adenopathy in children from five to twelve years of age. They found reductions ranging from 15 per cent to 42 per cent in children for whom diagnosis had been made, and in a group of other children of the same age range "diminished vital capacity and roentgenologic evidence of tracheo-bronchial adenopathy were found in 16 per cent of apparently normal white subjects." (p. 59) Data for the specific ages were not given.

Parsons, Wright, and Howell (92) made a clinical study of five children, four to seven and one-half years of age, diagnosed as anemic. All showed breathing capacity readings markedly lower than those of a control group of ten children, and lower than the norms from surface area given by Edwards and Wilson (41). Following treatment, three of the subjects increased their breathing capacity.

It may be of interest to mention an attempt to measure the breathing capacity of newborn infants made by Deming and Hanner (34). They used the apparatus described by Deming and Washburn (35) as an air-tight chamber connected with a delicate float-type spirometer with provision made for inserting the child in the chamber with the head out and the neck closed by an air tight collar. Excursions of the child's chest in breathing caused displacement of the air in the chamber, the amount of which could be measured. They considered that the maximal excursions made while the child was crying might serve to give an approximation of the breathing capacity. Using eighteen infants from one to eleven days of age, they found breathing capacities ranging from 121.0 to 181.1 cubic centimeters. (8 to 11 cubic inches.)

It is evident from this discussion of previous studies which have made mention of the breathing capacity of preschool children that little information concerning the reliability and significance of the test for this age range is available. No study has been concerned solely with preschool age children, the information concerning such children being obtained only incidentally to that for the school ages. In no study has an attempt been made to investigate the prob-

lems of administration specific to this age, although several investigators have pointed out that such problems exist. No study is available which investigates the relationship of this test to other measures of physical and mental growth during the preschool period. In short, almost nothing is known about the breathing capacity of preschool age children.

CHAPTER IV

THE SPIROMETER

The general design of the wet spirometer[4] has not changed since it was introduced by Hutchinson in 1846. The description he gave in 1852 might still be employed:

> "The Spirometer is merely a vessel or receiver, inverted in another vessel, which contains water, like an inverted wine glass in a tumbler of water; by means of a flexible tube, communication is made with the inverted receiver, and air is blown into it; the receiver then rises, assisted by counterbalance weights; the degree of ascent being according to the volume of air introduced. Such instruments have been known for 50 years past as Pulmometres; but hitherto, no table of the capacity of the lungs was worked out; therefore, the Pulmometres never became useful." (64, p. 18)

More recently Turner (117) has described the requirements of a reliable spirometer as follows:

> "A thoroughly good spirometer is . . . the first essential for getting accurate measurements of vital capacity. The characteristics of such a machine are a light bell, accurately counterpoised, and moving without friction so that it starts easily and shows no back pressure at the end. It is thus able to receive the *whole* expiration and not cheat the subject out of the last few hundred cubic centimeters by resistance to the entrance of the air at a time when the available energy of the expiratory muscles is at its lowest. The good spirometer also shows a mouthpiece and connecting tubing of sufficient aperture so that the air can be received by the machine at any speed which the subject finds easy to use. . . . The tubing should be of the size used in the basal metabolism apparatus, about 2 cm. in internal diameter, with a mouthpiece whose orifice, usually oval in shape, is equally large." (p. 59)

Among the factors affecting spirometer readings, the following have been given consideration by investigators who wished to use the spirometer for careful, scientific measurement.

[4] Dry spirometers are also available. They have never attained widespread use, however, and few scientific studies of breathing capacity have been based on them. No discussion of them will be given in this paper.

1. The difference in air pressure inside and outside the bell: Since the force of the breath must overcome the friction of the system and the excess of the weight over the counterweights, the air pressure inside the cylinder will be greater than that outside the cylinder, giving a reading slightly smaller than the true volume. Hutchinson (64) attempted to correct for this by inserting a U-tube manometer partially filled with liquid in such a manner that one arm was in communication with the air in the spirometer and one with the outside air. The position of the spirometer was adjusted by hand until the liquid stood at the same level in both arms of the tube. Bowen (23) studied the same problem, and found the error to be from 1 to 3 per cent of the volume. He also suggested the use of the U-tube manometer to aid in correcting the recorded volume.

2. The difference in temperature between the breath and the water through which it passes: If the water in the tank is colder than the breath, condensation takes place and the volume is reduced. Hutchinson (64) provided a table for correcting for this reduction based on a change of 1/500 of the bulk of air for each degree of change in temperature, but considered such a correction necessary only when differences in temperature were extreme or "in case of doubt." McCloy (77) constructed a similar table, adding a paper scale to be pasted on the vertical scale of the standard Narragansett spirometer from which the corrected volume could be read directly. Bowen (23) suggested that a Welsbach burner and thermostat be employed to keep the water in the spirometer at a constant temperature of 37 degrees.

3. The resistance of the small air tube: Bowen (23) found that the use of a larger air tube did not increase the readings, since the strength of the respiratory muscles is sufficient to overcome a much greater resistance than that offered by the elastic tube.

4. Changes in atmospheric pressure: Bowen (23) called attention to the fact that the reading would be slightly affected by changes in atmospheric pressure and advised that barometer readings be taken into consideration, but made no specific suggestions as to how this might be done.

Some of these factors are of little practical consequence, and correcting for them only serves to add an illusion of greater accuracy to a measurement which is at best only an approximation. The correction for differences in temperature is small, and can be kept almost negligible if reasonable precautions are taken to keep the temperature of the water constant within 2 or 3 degrees. For the ordinary blow, the resistance of the small tube affects the read-

ing very slightly if at all. The effect of atmospheric pressure is probably not great enough to warrant the additional labor involved in correcting for it.

But the difference in air pressure inside and outside the spirometer may become a considerable factor in a poorly constructed instrument, particularly if the instrument is used with smaller children. Since the inertia of the system and friction are constants, the reduction in volume due to the force necessary to overcome this inertia will become proportionately larger as the breathing capacity decreases. This point was stressed by Edwards and Wilson (40) when they wrote: "A spirometer that offers minimal resistance to the egress of the air from the lungs is necessary for measuring the vital capacity of children." (p. 647)

In using the standard school spirometers with small children, two other problems may be noted:

1. Since the cross-section of the bell is great (7.8 inches in diameter for the Medart spirometer), the distance travelled upward per cubic inch of air exhaled is very small (.025 inches). The vertical scale is graduated in 10 cubic inch units, with five subdivisions per unit. These subdivision lines are very close together, and with the rather coarse indicator used, it is difficult to read the volume more accurately than to within 2 or 3 cubic inches of the true volume. For a breathing capacity of 200 cubic inches, an error of 2 cubic inches is slight, only about 1 per cent, but for breathing capacity of 40 cubic inches the error may be as great as 5 or 6 per cent.

2. From the standpoint of motivation the large cross-section of the spirometer is a further handicap. For a breathing capacity of 40 cubic inches the cylinder rises only 1 inch, and the child sees very little effect from the effort he has expended. If he exerts further effort and raises his score to 50 cubic inches, the cylinder rises only 1/4 inch higher, a difference which is hardly perceptible to the child.

When all of the above-mentioned factors were taken into consideration, it seemed that the standard spirometer was not suitable for use with small children if maximum and accurate records were to be obtained. Consequently, it was decided to build a new one better adapted for use with children of preschool age.

If the results to be obtained were to be comparable with those obtained at the older ages, no radical innovations could be made

in the design of the children's spirometer. Therefore, no new design was attempted. Instead, the spirometer was modified to meet the following requirements:

1. The cross section should be small and the excursion range correspondingly great.
2. The bell should be as light as possible and carefully counterweighted so as to offer minimum resistance to upward movement.
3. Resistance due to friction should be kept to a minimum.
4. The capacity should be great enough to permit the use of the instrument with children up to seven years of age.
5. The spirometer should be attractive in appearance.

The volume of the spirometer was determined by referring to the tables given by Meredith (87) and Boynton (24) showing ranges and means for breathing capacity of Iowa City boys and girls, respectively, from six to eighteen years. The maximum breathing capacity for eight-year-old boys given by Meredith is 135 cubic inches. The volume of the spirometer was set at 160 cubic inches.

Various combinations of cross-section area and vertical height for the cylinder were tried, a diameter of 5 inches and a height of 11 inches being selected as giving pleasing proportions and meeting the requirement that the cross section should be relatively small and the excursion range correspondingly great.

With these specifications, the spirometer shown in Figure 1 was constructed by J. G. Sentinella of the State University of Iowa. The upright cylinder is made of brass tubing 1/8 inch in thickness covered with black crystallizing lacquer. The uprights and pulleys are made of brass, with a smooth finish. The metal tubes are also made of brass. The bell is made of 1/64 inch brass sheeting, and has a clearance of 1/16 inch as it moves up and down. Fifty pound test linen fish line runs over the pulleys and connects the bell with the counterweights. The balance of the bell and the counterweights was carefully worked out so that the bell offers little resistance to upward movement. A slight puff is sufficient to start it on its upward rise.

Soft rubber tubing with .8 cm. inside diameter is attached to one extension of the inside vertical pipe, and the second extension is fitted with a cork which is removed when the air is being let out of the tank. The faucet attached to the lower part of the tank

is for convenience in emptying the water from the spirometer. The individual wooden mouthpieces manufactured by Stoelting and Company for use with a large spirometer fit the rubber tubing. A new mouthpiece was used for each child.

The vertical scale is graduated in 2 cubic inch units. The dis-

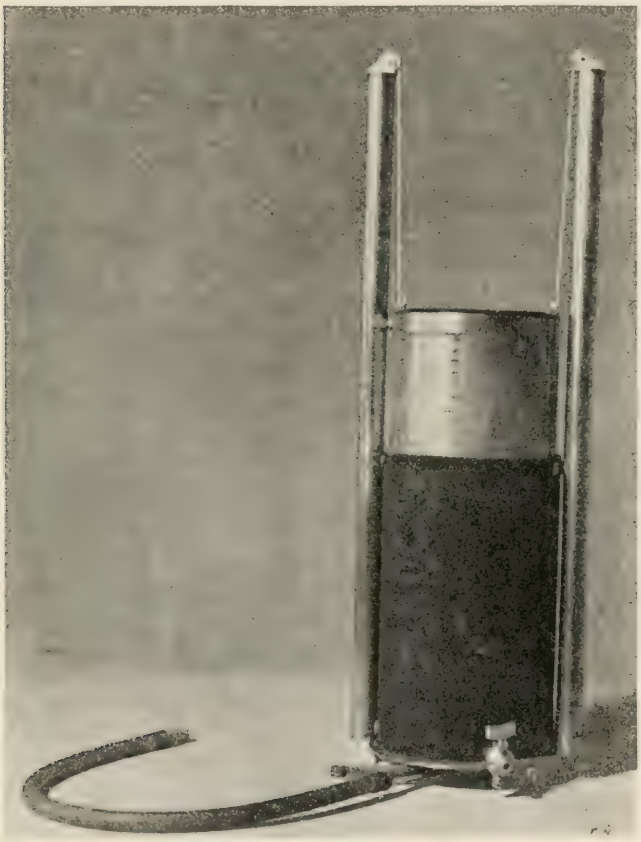

FIGURE 1. THE SPIROMETER.

tance between two cross lines is .1 inch, so that the record may easily be read to the nearest cubic inch.

The spirometer measures 21.5 inches from the base to the top of the pulleys and has an over-all diameter of 5.4 inches. It weighs 11 pounds when empty, and can be transported easily.

No provision has been made for a U-tube manometer to measure

the difference in air pressure inside and outside the spirometer. With the light bell, carefully counterweighted, such a difference is not great. To attempt to adjust the height of the bell after each trial would be very time-consuming and would greatly complicate the administration of the test. Since the spirometers used for measuring breathing capacity of elementary and high school children are very seldom equipped with this pressure gauge, it was decided to dispense with it in the preschool instrument as well.

Some consideration was given to the possibility of using a motivating device to insure maximum effort. Suggestions included painting pictures on the bell so that they would come into view as the bell moved upward, or painting the bell in horizontal stripes of bright color so that each succeeding rise of 5 cubic inches would bring another color into view. These ideas were discarded, however, since it was likely that the instrument would be used with two or more children at a time. Such devices would make very evident any marked differences in the breathing capacity of two children, and this might result in embarrassment for the smaller child, which would tend to reduce co-operation at later trials.

It is believed that the instrument as described above meets the requirements of a good spirometer for use with preschool children. The cross section is small, and the excursion range is correspondingly great. Records up to 160 cubic inches may be read accurately to the nearest cubic inch. The bell is light and carefully counterweighted to move easily, the pulleys turning with a minimum of friction. The spirometer as a whole is attractive in appearance and is small enough to be carried about easily.

CHAPTER V

ADMINISTRATION OF THE TEST OF BREATHING CAPACITY TO PRESCHOOL CHILDREN

TESTING PROCEDURE

The method of administering the test of breathing capacity as described by Hutchinson in 1852 appears to have been used with only minor variations by all succeeding investigators. He advised:

> "Let the person to be examined . . . stand perfectly erect . . . with the head thrown well back; slowly and effectually fill his chest with air, or inspire as deeply as possible, then put the mouthpiece between the lips, (standing in the same erect position), holding it there sufficiently tight, as not to allow any breath to escape . . . immediately the patient empties his lungs, and slowly makes the deepest expiration." (64, p. 15-16)

Dreyer and Hanson (38), in 1931, recommended the use of a nose clip, and seated their subjects on a high stool. Wilson and Edwards (126), in the same year, recommended the use of the sitting posture. However, such modifications of Hutchinson's directions are seldom found.

As to the manner of exhaling into the spirometer, two comments are of interest. McCloy (79) wrote:

> "The subject should thoroughly understand the technique of blowing into the spirometer. No standardized instructions as to technique have seemed desirable, since the standardized techniques are apt to act as much as intelligence tests as standardizers of the breathing capacity. The examiner should see that the subject really does know what he is expected to do, and that he does it to the limit of his capacities. A little competition with himself and other subjects will frequently work wonders." (p. 82)

Whipple (125) found:

> "There is a certain knack in making a maximal spirometer record; some children may exhibit it; others not. In particular, to get a good record, the expiration must be neither too fast nor too slow, and an extra effort must be made just at the end of both inspiration and expiration to utilize the available lung-capacity to the utmost." (p. 73)

There has been little unanimity concerning the number of trials which should be used in obtaining an acceptable estimate of the breathing capacity of an individual. Giving three trials and recording the best score has been the most popular method. This was used by Myers (90), Meredith (87), Garrett and Schneck (46), Pyle (99), and Whipple (125). Gates (48) stated that he gave "three or more trials to new children and once to those who had the 'knack.'" (p. 333) Wilson and Edwards (126, 127, 40, 41) used three to five trials, Jersild (67) the best of four trials, and Dreyer and Hanson (38) the best of five trials, stating that the best of five trials was "about 5 per cent greater than the mean of the observations." (p. 10) Christopher (28) and Smedley (108) gave repeated trials, Christopher stating:

> "In this test the subject was allowed repeated trials, until he fell short of his former endeavors. The aim of those making the test was to get the best record that it was possible for each pupil to make." (p. 32-33)

Among the investigators who did not specifically state how many trials were given, Emerson and Green (42) reported that they used only those readings "which came within 20 c.c. of each other," and Stewart (110) recommended the use of competition in groups, recording the best trial. He wrote: "In instances where the cooperation was unsatisfactory, the data were discarded." (p. 452)

As to the feasibility of administering the test to children under five years of age, Meredith (87) has described the early policy of the Iowa Child Welfare Research Station:

> "The factors of motivation and comprehension of instructions prohibit the use of this measurement during the early years. At the Iowa Child Welfare Research Station laboratories breathing capacity is not taken below five years of age." (p. 128)

For children between five and seven years of age, opinion appears to be divided. Jersild (67), working with children of these ages commented:

> "There were frequent indications that the subjects were responding to full capacity during the training period." (p. 39)

Wilson and Edwards (127) wrote:

> "Contrary to the more or less general opinion, children use

> the spirometer with surprising ease and intelligence. A child of six years, of average mentality, in the majority of instances requires only a single demonstration. The number of cubic centimeters registered will be within fifty on repeated satisfactory trials.'' (p. 1107-1108)

On the other hand, Roberts and Crabtree (102), and Emerson and Green (42) did not recommend the use of the test at these ages. Roberts and Crabtree claimed:

> ''In children of 6 years and under the vital capacity readings are unsatisfactory, for the reason that it is difficult to secure the cooperation of the child.'' (p. 1950)

Emerson and Green stated that:

> ''. . . proper coaching of the children and experience are of greatest importance in securing reliable results. Children below 7 years do not cooperate well. (p. 203) . . . Determinations of vital capacity below seven years of age are unreliable.'' (p. 211)

Jersild (67) investigated the effect of practice on breathing capacity performance, using twelve practice and twelve control subjects, five to seven years old. The practice group was given trials three times a week from November to February. He found that the most pronounced improvement was made during the first six trials, which, he believed, ''supports the view that training provided improvement in technique rather than a change in capacity.'' (p. 42)

From this survey of the literature pertaining to the administration of the test of breathing capacity it would seem that there are several questions to be answered before any standardized procedure may be recommended for administering the test to preschool children. The more important of these questions are:

1. What procedure should be followed in administering the test?
2. How should the initial presentation of the test be made in order to secure the best understanding and co-operation?
3. How may the test be motivated in order to secure maximum inhalation and exhalation?
4. Are the results affected by the time of day at which the test is administered?
5. How many trials are necessary to secure a maximum, reliable score? Should all of these be given on the same day

or should they be spaced over several days to provide for practice and learning of technique?

Not all of these questions may be answered quantitatively. Some may be answered only as a result of experience with the test and with preschool children. Results from exploration of the problems raised are presented below.

What procedure should be followed in administering the test? Traditionally the test has been administered with the subject standing erect, taking a deep breath, placing the mouthpiece in his mouth, and blowing as long as possible. Dreyer and Hanson (38), and Wilson and Edwards (126), have seated their subjects on a stool, and Dreyer and Hanson have closed the nostrils with a clip. The sitting position offers no clear advantage, and in certain cases it might conceivably interfere with the effective use of the respiratory muscles, particularly the diaphragm. Theoretically, the nose clip should increase the amount of air exhaled through the mouth. However, the factors of discomfort, distraction, and possible interference with inspiration were considered to more than outweigh the possible advantages of the nose clip. Particularly with small children, many of whom would undoubtedly resent this discomfort and refuse to co-operate as a result, the use of the clip seemed to offer too little promise to merit experimentation.

In this study the test has been administered with the child standing erect, taking a deep breath, placing the mouthpiece in his mouth, and exhaling as completely as possible into the tube. No provision has been made for the small amount of air which might escape from the nose. Figure 2 shows a child using the spirometer in this manner.

How should the initial presentation be made in order to secure the best understanding and co-operation? As to general method, three courses are possible. (1) The large group method: The children may be assembled as a group and the spirometer and its use explained to them; they may then be taken individually for testing. (2) The small group method: Small groups of three or four children may be taken to the testing room and the test explained to them, each of them being given an opportunity to try the test at that time. (3) The individualized method: One child may be taken to the testing room, the test may be explained, and then administered. Each of these methods was tried in the initial stages of the study.

1. The large group method was tried first with about twenty Junior Primary children. The teacher introduced the experimenter and explained that she was going to tell the children about a new game. The children were curious about the spirometer, and there was no difficulty in keeping their interest for the first five minutes.

FIGURE 2. ADMINISTERING THE TEST OF BREATHING CAPACITY.

After the explanation and demonstration had been given by the experimenter, more than half of the children volunteered to try the test. Two were allowed to do so, and the others were told that they could go one by one to the testing room to try it.

A similar procedure was tried with ten three-year-olds, but with less success. The children tried to crowd around the instrument and wanted to see it more closely. When the first volunteer was chosen, he failed to master the technique of blowing out and kept sucking in. This was embarrassing for him. Attempts by the experimenter to correct his technique gave the other children the impression that blowing into the spirometer was a very difficult thing to do, and they were reluctant to try when their turns came.

In general, it was concluded that this method carries with it certain hazards. If all goes well with the demonstration, it has the advantage of arousing the interest of the children so that they are anxious to try the test. If anything goes amiss with the demonstration, the opposite effect is created. This initial demonstration saves very little time in the individual testing, since each child's curiosity about the instrument must be satisfied when he comes to the testing room.

2. The small group method was used with twenty four-year-olds and ten three-year-olds. The procedure was similar to that above, except that only three or four children were taken to the testing room, the test was explained to them as a group, and then they were given turns in trying it. While the demonstration was being given, the children crowded around the table, the experimenter, and the spirometer, making the whole situation confused and difficult to direct. It was not possible to give one child several turns, correcting his mistakes, and trying to get maximum results, as the children were impatient for their turns. Letting them take "turns" necessitated changing the mouthpiece many times as well as much shifting about of the children to get them into proper position.

It was thought that using small groups would make it easier for the timid children who might be a little frightened by the strange instrument. However, the fear of failure in the presence of the other children made some of the children refuse to try the test, particularly when some other child in the group found it slightly difficult. This made it necessary for the experimenter to rebuild rapport with these children for subsequent testings.

3. The individualized method was used with all the rest of the

subjects. They were taken to the testing room one at a time, (sometimes two at a time if they preferred it). The experimenter explained and demonstrated the test, explained about the clean mouthpiece, and let the child try it. All questions about the spirometer were answered as accurately as possible. For any who wished it, the spirometer was pushed to the top, the bell was tilted and the child was allowed to touch the water. Then he was shown where the air came in and allowed to hold his hand over the inside vertical tube while he blew. This was time consuming, but seemed worthwhile in that the more familiar the children became with the instrument, the more willing they were to co-operate in the testing. As much time as was necessary was taken to correct mistakes and get the necessary concepts clear in the child's mind. Since the child had no one with whom to compare himself, he was not discouraged when his first blows raised the bell only a short distance, and could be encouraged to try to blow harder without being made to think that he had failed. With only one or two children being tested, the experimenter was more free to adapt her methods to the specific needs of the individual.

On the whole, it was felt that the individual method was the most satisfactory way of presenting the test, both for the child and for the experimenter. By taking one child at a time it is easier to establish confidence and to correct any bad habits before they become fixed.

With a small proportion of the children it was difficult to get them to understand the difference between taking in a breath and exhaling it. Several devices were tried. The idea of blowing a whistle was not well understood by the smaller children. Imitations of a locomotive puffing were not successful, because the children got the idea of several consecutive short puffs instead of a long blow. The most successful idea seemed to be to liken the spirometer to a balloon. This led to a demonstration which ran something like this:

> "This game is like blowing up a big balloon. You know how we do that? We take a big breath like this (demonstrate) and then we blow (demonstrate) until we can't blow any more. Now watch and see what happens when I blow. I take a big breath like this (inhaling deeply with the mouth open) and then I blow (indicating with the hand the rising bell of the spirometer) until I can't blow any more. Now let's see how high you can make it go. I'll put this clean mouthpiece in

for you. Then—big breath (breathing deeply with them) and then blooooooow until you can't blow any more.''

(It takes a little practice to be able to create the illusion of first taking a very deep breath and then, blowing only as high as one expects the child to go, appearing to have blown out all of the air in the lungs.)

How may the test be motivated in order to secure maximum breathing capacity records? Since the score made on the test depends on the voluntary effort of the child as well as on the amount of air available in his lungs, it is important that the experimenter keep the child interested in trying to do his best on the test, and that errors in technique which might result in lower records be eliminated as far as possible. No controlled experimentation was carried on to determine the relative value of certain devices, but the following seemed useful.

1. The most important motivator is the real interest of the experimenter in the child and in each attempt he makes. Children are quick to sense boredom or impatience in the experimenter and respond accordingly, but they respond just as quickly to any real enthusiasm, and will try harder when encouraged by someone who seems to feel that the results of their efforts are important and interesting.

2. Setting a mark for them to aim at was found to be helpful when they were stopping before they had completely exhaled. The usual procedure was to say, ''I think you could blow as high as this'' or ''Yesterday you blew way up to here,'' indicating a point with the pencil. ''I'll hold my pencil here and you see if you can make the pointer push it off.'' This was also useful in correcting certain minor faults in technique, since the child's attention was concentrated on getting the pointer up to the pencil and he forgot about the difficulties he had been having.

3. Taking a deep breath to remind the child to do likewise before each attempt is almost essential with young children. If the experimenter fails to say ''big breath, now,'' suiting the action to the word, the children will often start to blow before inhaling, in their haste to make a record.

Other minor problems, which were met less frequently, and suggestions for overcoming them are listed below:

a. Puffing or trying to reach the top in a series of short breaths. The experimenter would take another mouthpiece and

say, "You blow with me this time. We'll both take a deep breath and see who can keep blowing the longest."

b. Blowing with the mouth slightly open. The experimenter would place a finger under the child's chin and gently force the mouth shut.

c. Blowing out before getting the mouthpiece in the mouth. The experimenter would hold the tube and quickly place the mouthpiece in the child's mouth at the proper instant.

d. Sucking instead of blowing. After a few attempts at sucking instead of blowing the correction is usually made spontaneously, but this correction was facilitated in some cases by the experimenter taking the child's hand and blowing on it, then placing it in front of the child's mouth for him to do the same.

e. Getting the tongue in the aperture of the mouthpiece. When this happened, testing was discontinued for a few minutes and when it was resumed the child's attention was attracted to the pencil held against the scale so that he was not conscious of his tongue.

f. Hunching the shoulders and getting tense as a result of trying too hard. Testing was discontinued when this occurred, and the next day no mention was made of trying to make a certain record until after the child was blowing easily.

g. Inhaling through the nose near the end of the blow. It is possible to increase the score by several cubic inches in this manner. Since this seldom happened and it never appeared to be done intentionally it seemed better not to mention it than to call attention to the possibilities of making larger scores by this method. The experimenter tried to watch the children and discard the score if such inhalation occurred.

At all times the experimenter felt it more important to keep the children happy and interested in the situation than to try to obtain a record on any given day, in the hope that better records would be the eventual result. This proved to be the case in many instances, for some of the youngest children who did not succeed in making a successful blow on the first day's testing seemed to have no difficulty on the second day. Only five children of all those tested failed to master the technique, and all of these were under three- and one-half-years of age.

That the children were really interested in the test was evidenced in several ways. Mothers reported that the children talked about blowing at home. They asked questions of the teachers and the experimenter such as: "Isn't the whistle lady coming today?" "How far can little babies blow it?" "Can anyone blow it all the

way to the top? Can my daddy do it? Can you do it? Show me." "Did I do more than John?", etc. They seemed to feel a personal ownership in the instrument, and a new cork or tube or a different colored pulley line were sure to be commented on by at least half of the children. As the testing proceeded and they became familiar with the test, many of the four- and five-year-olds would come into the testing room, get their own mouthpiece, put it in, take their big breath, and blow without instruction from the observer.

It is the writer's opinion that this interest on the part of the children, which was carefully fostered by the experimenter, played a large part in the successful administration of the test, and that any testing situation which fails to take it into account will result in markedly lower scores for preschool children.

Are the results affected by the time of day at which the test is administered? Two approaches were made to this problem, the first using three adult subjects and the second using twenty-one five-year-old children.

1. Three adults who were willing to co-operate measured their breathing capacity at intervals of about two hours for a period of six days. Several trials were taken at each testing, and every effort was made to secure the maximum record possible. When these records were tabulated it was found that the range of daily variations for the best score made on each set of trials was from 205 to 224 for subject A, from 218 to 240 for subject B, and from 224 to 253 for subject C.

The records for each subject were grouped as to time of day, the means being:

Time of Day	Mean
8:00 to 10:00	229.3
10:00 to 12:00	228.7
12:00 to 2:00	230.0
2:00 to 4:00	231.7
4:00 to 6:00	227.0

Using the method of analysis of variance,[5] it was found that $F = 1.14$ for the *time* and *interaction* variances. This is not significant,

[5] Throughout this study frequent use has been made of the statistical procedures of analysis of variance and co-variance. The reader unfamiliar with these techniques is referred to R. A. Fisher, *Statistical Methods for Research Workers* (London: Oliver and Boyd, 1938. Pp. xv, 356). A more recent exposition of these methods as they apply to educational research will be found in E. F. Lindquist, *Statistical Analysis in Educational Research* (New York: Houghton Mifflin, 1940. Pp. xiii, 266).

indicating that the time of day at which the records were taken had no significant effect upon the scores made.

2. It was not possible to conduct a similar experiment with the children since they are in attendance for only half a day. Consequently, it was necessary to investigate the morning and afternoon effects separately.

Twelve Junior Primary subjects were tested between 9:00 and 9:30 and again between 11:15 and 11:45 on the same day. The means of the scores made were:

Time of Day	Mean
9:00 to 9:30	73.2
11:15 to 11:45	74.5

The differences between the individual scores were computed and compared with the differences between scores made by the same children between 9:00 and 9:30 on two consecutive days. The difference between the means of these distributions was 1.91 cubic inches. A "t" of .87 indicated that they were not significantly different.

Similarly nine other Junior Primary children were tested between 1:00 and 1:30 and again between 2:30 and 3:00 on the same day. The means were:

Time of Day	Mean
1:00 to 1:30	75.9
2:30 to 3:00	73.9

The differences were computed as above and compared with the differences between scores made between 1:00 and 1:30 on two consecutive days. The difference of the means was 1.66, and "t" was .76, which is not significant.

From these two experiments it was concluded that the variation introduced by administering the test at different times during the day was no greater than the variation due to administering the test on different days.

How many trials are necessary to secure a maximum, reliable score? Should all of these be given on the same day or should they be spaced over several days to provide for practice and learning of technique? Two subdivisions were made of this problem: (a) to determine how many trials should be used on any day, and (b) to determine how many days of testing were necessary.

1. The scores of forty-five children, fifteen at each age from three

to five years, were studied. Each child was tested on five different days and was given a minimum of five trials on each day. The scores made on these five trials were examined and the number of the trial on which the best score occurred was noted. These are tabulated below:

Best Score Made on Trial	Years 3	4	5	Total
First	20	8	9	37
Second	15	16	16	47
Third	9	21	17	47
Fourth	20	9	16	45
Fifth	11	21	17	49
Total	75	75	75	225

It is evident from this tabulation that one or two trials of the test on any given day is not enough to insure maximum readings for that day from most of the children, since two-fifths of them made their best record on the fourth or fifth trial. It is also possible, of course, that if more than five trials were given, some children would make their best scores on the sixth, seventh, or later trials. (This happened in a few instances when children asked to be allowed to try again. But in general, after the children were familiar with the test they did not ask for more than five trials.)

The total distribution does not differ significantly from that which would be expected if chance alone were operating to determine upon which trial the best score would be made ($X^2 = 1.93$). Hence it appears reasonable to conclude that fatigue and loss of interest are not factors tending to decrease the score in five trials. This would indicate that five trials on each day are not too many, and that better scores are made by some of the children than they would have made if only one, two, three, or four trials had been used.

Five trials on any one day were selected as the standard procedure, being administratively feasible, and giving the child a reasonable number of attempts without producing fatigue or boredom.

2. The best score made on each of six days (five trials on each day) was tabulated for forty-seven children aged three to five years. From these tabulations the following scores were determined:

Score	Mean
Best of 6 days	54.0
Best of the first 5 days	53.2
Best of the first 4 days	52.4
Best of the first 3 days	51.0
Best of the first 2 days	50.1
On the first day	48.7

It is evident from this tabulation that improvement occurs after the first day, since the mean of the best scores for six days is 54.0 as compared with 48.7 for the first day. For the first four days of testing the average increase per day is 1.2 cubic inches and for the fifth and sixth days, .8 cubic inches. While it is likely that further increases would occur if the tests were given for seven or eight days, it seems probable that most children have achieved their best record by the sixth day, and that further increases would be slight.

The individual records were studied for each of these children. It was noted that in a few instances the best score was markedly greater than any of the other scores. This suggested the possibility that this score represented an error. It was possible that the bell of the spirometer had not been pushed down to the zero point, or that the child had taken an extra inhalation as he reached the limit of his "blow," or that a mistake had been made in recording the score.

If a sufficient number of trials were given, the best score should not differ greatly from the second best score. To test this hypothesis, the second best scores were determined as follows:

Score	Mean
Second best of 6 days	51.4
Second best of 5 days	50.3
Second best of 4 days	48.6
Second best of 3 days	47.1

Again the increment from the fifth to the sixth day, 1.1 cubic inches, is less than the earlier increments, which average 1.6 cubic inches, indicating that while improvement was still being made on the sixth day, it was becoming less.

The best of six days' scores was compared with the second best of six days' scores for each child. The range of differences was from 0 to 9 cubic inches. For 60 per cent of the cases the difference was 0, 1, or 2 cubic inches. For 85 per cent of the cases it was 4 cubic inches or less. It seemed likely that some of the differences

greater than 4 cubic inches were due to an error in the higher score.

When the second best of six days' scores was compared with the average of the three best scores for each child, the mean difference was .002 cubic inches, which is obviously not significant.

After studying all of these relationships, it was decided that the second best score made in six days of testing would constitute a dependable estimate of the breathing capacity of children at these ages. It is recognized that this choice is an arbitrary one and that arguments might be advanced for several other choices of scores. But subsequent evaluation of the individual records of more than two hundred children has confirmed the writer in the opinion that this choice, while conservative, is a defensible one.

In this study, then, the breathing capacity score was derived as follows: Each child was tested on six separate days, each day's testing consisting of at least five trials. The best score made on each day was recorded, and from these six records the second highest was selected as the breathing capacity score for that individual. In a few cases where the results of only five days' testing were available, the second best of five days' scores was used.

RELIABILITY OF THE TEST

Considering the long history of breathing capacity tests, both for research purposes and for routine school testing, it is surprising to find how few investigators have attempted to determine the reliability of the scores obtained. Only three studies, Jersild (67), Rogers (103), and Schwarz, Britten, and Thompson (106), have reported on the reliability of the test of breathing capacity. Of these determinations, only Jersild's apply to the preschool ages.

Jersild administered the breathing capacity test on four consecutive days, giving four trials each day, to two groups, each consisting of twelve children, ages five to seven years. Product-moment correlations of the best score on the first two days with the best score on the last two days were .94 and .79 for the two groups respectively. Rogers reported a reliability of .97 for the test based on the correlation of scores made in September with those made in May by 140 boys, ages 12.75 to 19.91 years. Schwarz, Britten, and Thompson obtained a correlation of .94 for scores made in February with those made in May by thirty-four high school boys, ages thirteen to seventeen years.

In the present study, the investigator gave five trials to each

child on each of six days and the best score for each day was recorded. The best score made on either the first, third, or fifth day was compared with the best score made on the second, fourth, or sixth day for each age-sex group. The differences ranged from 0 to 16; 50 per cent were 2 cubic inches or less, and 90 per cent were 6 cubic inches or less. The correlations between these scores are shown below:

Age	Boys		Girls	
	Number	r	Number	r
2 years, 6 months to 3 years, 5 months	18	.798*	22	.870
3 years, 6 months to 4 years, 5 months	31	.907	23	.888
4 years, 6 months to 5 years, 5 months	44	.932	28	.906
5 years, 6 months to 6 years, 5 months	22	.960	18	.897
All children	115	.966	91	.963

* It is recognized that the third decimal place has little meaning in correlations based on such small numbers of cases. However, all correlations in this study were routinely computed to three places since many of them were later used in partial and multiple correlations.

There is some tendency for the size of the correlations to increase with the age of the children, and a general tendency for the correlations for the boys to be higher than those for the girls. However, these trends are not marked; all correlations with the exception of that for three-year-old boys being approximately .90.

These correlations compare favorably with those of .94 and .79 given by Jersild for children from five to seven years of age. Rogers' value of .97 for scores obtained over an age range of seven years with 140 high school boys is only slightly higher than the values obtained for the one year age groups, and is no higher than the correlation obtained when the scores for the four year age range are put in one distribution.

These correlations seem high enough to indicate: (1) that reliable results may be obtained from tests of breathing capacity given over six days to children from two and one-half to six and one-half years of age; (2) that such results are no less reliable than those obtained when the test is administered to older children.

CHAPTER VI

BREATHING CAPACITY AS RELATED TO CHRONOLOGICAL AGE

AGE MEANS FOR BREATHING CAPACITY

The average breathing capacity for children of elementary and high school age has been reported by numerous investigators, but only seven studies have included averages for preschool children. In each instance these data on preschool children have been only incidental to the main purpose of the study. In Table 1 is given a description of the data on which the principal studies are based. The studies are arranged chronologically with reference to date of publication.

In Tables 2 and 3 the average breathing capacity found for each age by each of these investigators is given. An attempt has been made to arrange these averages in order of magnitude. Since the order is not always the same for every year of age, the values reported at ten years have been selected as the point of reference. The values as given may be slightly misleading in some instances, since some investigators have taken age to the last birthday and some to the nearest birthday, while others have failed to indicate the limits of the age groupings. In cases where the investigator has specifically defined the age interval used, this information is given. All reported averages have been changed into cubic inches so that they may be readily compared. The number of cases on which the reported averages are based is given for the preschool ages.

Taking the means for ten-year-old boys as representative, the values reported may be grouped as: high (above 110), intermediate (99 to 110), and low (below 99). High values were reported by Baldwin (13), (14), (16), Stewart (110), Abernethy (1), Meredith (87), Schwarz, Britten, and Thompson (106). Except for Baldwin's 1914 study, all have been completed within the last two decades, and all except those of Stewart, and Schwarz, Britten, and Thompson have been made on private school children. Geographically the subjects are distributed from New York to California, including Chicago, Iowa, and Minneapolis. There is a tendency to use at least three trials in these later studies.

Table 1
Description of Data of Principal Studies Reporting Age Means for Breathing Capacity of School Age Children

Investigator	Date	Cases		Age Range, Years	Subjects	Trials
		Boys	Girls			
Gilbert (49)	1894	594	c650	6 to 17	Not described	? 1
Gilbert (50)	1897	c650	c650	6 to 18	Iowa public schools	? 1
Christopher (28)	1900	609	603	4 to 16	Chicago public schools	Repeated
Smedley (108)	1901	2,788	3,471	4 to 18	Chicago public schools	Repeated
Hastings (57)	1902	6,711	6,442	5 to 18	Nebraska public schools	2 to 3
DeBusk (32)	1913	105		7 to 16	Colorado private school	?
Baldwin (13)	1914	25 to 40 each age	25 to 40 each age	7 to 17	Chicago and New York private schools (repeated measurements on same children)	?
Stiles and Graves (114)	1915	751	867	6 to 17	Southern "City of X" public schools	?
DeBusk (33)	1917	104	96	7 to 15	Colorado private school	?
Baldwin (14)	1921	?	?	7 to 17	New York private school	?
Stewart (110)	1922	1,289	1,220	4 to 18	Minneapolis public school	Competition
Holzinger (63)	1924	3,373		6 to 60	English (Galton's original data, collected many years earlier)	
Baldwin (15)	1925	300	270	7 to 15	California "geniuses"	?
Baldwin (16)	1928	22,913	10,737	5 to 18	Composite	?
Schwarz, Britten, and Thompson (106)	1928	2,162		3 to 60	New York public schools	3
Collins and Clark (29)	1929	15,000	15,000	6 to 15	"Old Americans" from all sections of United States	3 to 5
Kelly (70)	1933	3,820	2,547	12 to 18	Baldwin's data, principally Iowa private schools	
Meredith (87)	1935	4,307		5 to 18	Iowa private school	3
Boynton (24)	1936		1,966	6 to 18	Iowa private school	3
Abernethy (1)	1936	179 repeated measurements		8 to 18	Chicago private school (repeated measurements on same children)	?
Dimock (37)	1937	200		12 to 16	Chicago Y.M.C.A.	3

Age Means for Breathing Capacity for Boys of School Age (Reduced to Cubic Inches and Rounded to the Nearest Cubic Inch)

Investigator	Age, Years																Age Interval Used
	N	4	N	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Hastings (1902) (57)			(202)	41	51	61	70	81	90	101	111	124	140	161	191	221	222	
Gilbert (1894) (49)					56	66	73	83	91	104	114	120	125	161	187	204		
Smedley (1901) (108)[1]	(41)	45	(70)	57	62	71	80	90	98	106	115	129	146	165	190	213	223	11 years, 0 months to 11 years, 11 months
Christopher (1900) (28)	(16)	44	(26)	57	72	76	85	90	99	109	120	138	154	165	193			11 years, 0 months to 11 years, 11 months
Gilbert (1897) (50)					60	72	85	90	99	122	121	136	154	182	194	233	231	
Stiles and Graves (1915) (114)[2]					64	74	83	88	102	109	125	137	154	177	200	213		
DeBusk (1913) (32)						67	91	105	105	116	121	139	149	185	200			11 years, 0 months to 11 years, 11 months
Holzinger (1924) (63)					74	81	88	97	106	116	127	139	153	170	190	206	228	11 years, 0 months to 11 years, 11 months
DeBusk (1917) (33)						76	93	92	107	122	133	143	149	182				11 years, 0 months to 11 years, 11 months
Collins and Clark (1929) (29)					65	74	86	96	107	118	129	144	162	175				
Baldwin (1921) (14)						79	88	99	109	121	133	149	169	196	224	247		
Baldwin (1914) (13)[3]						77	86	96	112	120	126	134	151					
											123	139	163	192	213	236		11 years, 0 months to 11 years, 6 months
Schwarz, Britten, and Thompson (1928) (106)	(14)	49	(36)	56	65	78	90	105	112	125	139	153	171	203	228	248	251	11 years, 0 months to 11 years, 11 months
Stewart (1922) (110)	(6)	48	(20)	57	71	79	90	105	115	122	133	150	166	193	209	230	240	
Baldwin (1925) (15)[4]						79	94	113	115	129	145	157	181	213				
Baldwin (1928) (16)					72	82	94	106	116	124	137	153	179	207	256	269	278	10 years, 6 months to 11 years, 5 months
Meredith (1935) (87)[5]			(64)	67	72	79	92	103	116	128	142	157	180	204	227	247	257	10 years, 6 months to 11 years, 5 months
Abernethy (1936) (1)							102	104	127	135	146	165	189	212	238	253		Measured on birthday
Kelly (1933) (70)											151	167	183	213	235	259	270	10 years, 6 months to 11 years, 5 months
Dimock (1937) (37)											150	175	200	223	253			

[1] "Birthday Norms," adjusted to make the mean age exactly 6 years, 6 months, 7 years, 6 months, etc.
[2] Dry spirometer used.
[3] Children measured at half-year intervals.
[4] Means for tall, medium, and short children reported. Those for medium children given here.
[5] Five-year-old group five years, six months to five years, eleven months of age. Six-year-old group six years to six years, five months of age.

Table 3
Age Means for Breathing Capacity for Girls of School Age (Reduced to Cubic Inches and Rounded to the Nearest Cubic Inch)

Investigator	Age, Years																Age Interval Used
	N	4	N	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Hastings (1902) (57)			(183)	35	43	51	60	70	77	82	94	106	113	123	131	151	150	
Gilbert (1894) (49)					50	54	66	73	82	83	104	105	105	116	115	119		
Gilbert (1897) (50)					56	62	70	82	84	91	103	118	119	128	131	128	138	
Smedley (1901) (108)[1]	(36)	46	(81)	52	58	65	70	78	86	93	102	111	123	132	128	142	143	11 years, 0 months to 11 years, 11 months
Christopher (1900) (28)	(21)	49	(37)	55	61	70	76	80	88	96	103	111	124	131	139			11 years, 0 months to 11 years, 11 months
Stiles and Graves (1915) (114)[2]					52	67	72	81	91	98	114	129	136	140	145	147		
DeBusk (1917) (33)						75	79	97	100	108	116	144	143	160				11 years, 0 months to 11 years, 11 months
Baldwin (1914) (13)[3]						71	82	87	101	114	128	146						11 years, 0 months to 11 years, 6 months
											125	134	154	165	177	183		
Stewart (1922) (110)	(9)	40	(26)	54	66	75	85	92	102	110	125	143	159	164	169	180	189	
Baldwin (1928) (16)					60	72	82	93	102	114	128	146	159	169	175	178	179	11 years, 6 months to 12 years, 5 months
Baldwin (1925) (15)[4]						73	89	99	103	116	128	156	163	191				
Baldwin (1921) (14)						73	79	91	104	113	127	144	157	173	182	185		
Boynton (1936) (24)					65	74	83	95	105	119	135	152	167	172	177	180	179	11 years, 6 months to 12 years, 5 months
Collins and Clark (1929) (29)					65	74	86	96	107	118	129	144	162	175				
Kelly (1933) (70)											129	147	158	168	173	181	180	11 years, 6 months to 12 years, 5 months

[1] "Birthday Norms," adjusted to make the mean age exactly 6 years, 6 months, 7 years, 6 months, etc.
[2] Dry spirometer used.
[3] Children measured at half-year intervals.
[4] Means for tall, medium, and short children reported. Those for medium children are given here.

Low values were given by Christopher (28), Smedley (108), Gilbert (49, 50), and Hastings (57). Each of these studies was done either at or before the turn of the century, the latest being published in 1902. All were done on public school children. Geographically, only the Middle West is represented; Chicago, Iowa, and Nebraska.

The intermediate values found by DeBusk (32, 33), Stiles and Graves (114), Holzinger (63), Baldwin (1921) (14), and Collins and Clark (29) tend to be chronologically intermediate between the high and low groups. (Holzinger's data, however, were collected many years earlier than they were reported.) This group includes both public and private school children from Colorado, the Southern "City of X," New York City, England, and "Old Americans" from large cities in all sections of the United States.

From this grouping of studies it would seem that the time at which the data were obtained is an important factor which is related to the average breathing capacity. There appears to be a tendency for the average breathing capacity to increase from decade to decade.

> Support for this point of view has been presented by MacKinnon and Jackson (84) and Newcomer (91). MacKinnon and Jackson reported that the average breathing capacity of male entrants to the University of Minnesota was 4187 c.c. in 1898 as compared with 4355 c.c. in 1929. Newcomer found the average breathing capacity of students entering Vassar College in 1901 to 1905 to be 166 cubic inches. For successive five year periods the mean breathing capacity increased steadily, reaching 180 cubic inches for those entering in 1916-1920.

A second possible factor would seem to be socio-economic status, since many of the higher values were obtained for private school children. But in these studies the private school factor is so closely related to the chronological factor that it is difficult to evaluate.

It is evident from this compilation of averages that to say that a child has a breathing capacity which is above or below the average for a given age is relatively meaningless unless reference is made to the sample on which the average was obtained. Similarly, any comparison of newly obtained averages must be made with averages obtained under relatively similar conditions on comparable children. Since the present data were collected in 1939 on private school children, it would seem that Meredith's and Boynton's means would be most useful for comparative purposes, particularly since

they are based on measurements of children from the same school system as those used in the present study. The means given by Baldwin (16), Stewart (110), Collins and Clark (29), and Schwarz, Britten and Thompson (106) are not based on data from private school children, but they are recent enough to make comparison profitable.

In the present study the mean breathing capacity in cubic inches for each year of age for each sex was calculated from scores derived from tests given on six days to each individual, as described previously. The means of these scores for each age-sex group are shown in Table 4.

From this table the following observations may be made:

1. There is an increase in breathing capacity from year to year for both sexes. The increases shown are somewhat irregular, as might be expected from the small number of cases on which they are based.
2. For boys, the mean breathing capacity at six years is 32.3 cubic inches greater than that at three years. The comparable gain for girls is 35.0 cubic inches.
3. For boys the mean breathing capacity at three years is 57 per cent of the mean breathing capacity at six years; for girls, 41 per cent.
4. There is an average annual increase of 10.7 cubic inches for boys and 11.7 cubic inches for girls.
5. At each year of age the greatest breathing capacity recorded is approximately twice the smallest.
6. There is no evidence that the breathing capacity scores are more variable at three years than they are at six years, as shown by the coefficients of variation for each age. The coefficients range from 12.2 to 20.8, the average being 17.0. They show fluctuations from age to age but no consistent trend toward increase or decrease.
7. The boys exceed the girls in mean breathing capacity at each age level. (This finding will be discussed in more detail later.)
8. For each age group, the obtained mean breathing capacity for six days of testing exceeds the mean of the scores made on the first day of testing.

It is of interest to compare these findings, both as to growth and variability, with those from comparable data at the older ages.

Meredith (87) found: "Between six and eighteen years breathing capacity (of boys) increases 267 per cent." (p. 48) Stewart (110) reported a gain of 197 per cent from six to sixteen for boys

Table 4
Central Tendency and Variability Values of Breathing Capacity in Cubic Inches at Each Year of Age from Three to Six

Age	Mean Age, Months	Number	Mean Breathing Capacity	Range	Standard Deviation	Coefficient of Variability	Per Cent of Mean at 6 Years	Mean of Scores of First Day
Boys								
2 years, 6 months to 3 years, 5 months	37	18	42.05	26 to 57	8.67	20.7	56.6	36.0
3 years, 6 months to 4 years, 5 months	48	31	51.24	42 to 70	6.78	13.2	68.9	48.9
4 years, 6 months to 5 years, 5 months	60	44	69.32	47 to 91	11.74	16.9	94.3	66.8
5 years, 6 months to 6 years, 5 months	70	22	74.32	50 to 100	15.44	20.8		72.2
Girls								
2 years, 6 months to 3 years, 5 months	38	22	33.86	23 to 44	6.33	18.7	49.2	30.8
3 years, 6 months to 4 years, 5 months	47	23	46.64	26 to 61	7.18	15.4	67.7	43.2
4 years, 6 months to 5 years, 5 months	58	26	56.62	36 to 81	10.16	17.9	82.2	53.0
5 years, 6 months to 6 years, 5 months	70	18	68.84	45 to 84	8.40	12.2		65.4

and 156 per cent for girls. The data of the present study indicate that breathing capacity approximately doubles between three and six years.

Stewart (110) computed prediction equations to estimate breathing capacity from age. For boys from four to nine years of age he found the best prediction for breathing capacity in cubic centimeters to be:

$$177.5 \text{ (Age in years)} + 81$$

For girls from four to eleven:

$$175.3 \text{ (Age in years)} - 57$$

These equations indicate that the annual increase for boys would be approximately 10.8 cubic inches, for girls 10.7 cubic inches. The present study shows an average annual increase of 10.7 cubic inches for boys and 11.7 cubic inches for girls from three to six years of age.

Somewhat different values for the average annual increase in breathing capacity were given by Roberts and Crabtree (102), who stated somewhat categorically that annual increases in breathing capacity are:

Boys

168 c.c. (10.2 cubic inches) from 6 to 13 years
360 c.c. (21.9 cubic inches) from 13 to 18 years

Girls

137 c.c. (8.4 cubic inches) from 6 to 9 years
236 c.c. (14.5 cubic inches) from 9 to 12 years
187 c.c. (11.4 cubic inches) from 12 to 15 years

Stewart (110) analyzed the fluctuations in the coefficient of variation for breathing capacity for his age means from four to nineteen years. He found that the coefficient of variation decreased during early childhood, increased about the period of puberty, and later declined. Meredith (87) similarly studied the coefficient of variation for boys from five to eighteen years. He found a coefficient of 18.3 for the five- and one-half-year-old group, which fell to 15.6 by nine years and rose to 21.0 at fourteen years, falling again to 15.9 at eighteen years. The average value over the entire age range was 17.5. Boynton (24) reported an average coefficient of variation of 7.7 for breathing capacity of girls over an age range of six to eighteen years, but this is obviously an error since for any

single year her lowest coefficient is 14.1. A recomputation of her data gives an average coefficient of variation of 17.8.

Since the average coefficient of variation found in the present study for the age period from three to six years is 17.0, it may be concluded that scores for the breathing capacity of preschool children are no more variable than those for school age children.

A graphic comparison of the means shown in Table 4 with those given by Baldwin (16), Stewart (110), Meredith (87), and Collins and Clark (29) for boys and Baldwin (16), Stewart (110), Collins and Clark (29), and Boynton (24) for girls is made in Figure 3.

It will be noted that the means of the present study for boys are higher than those given by any of the other investigators. A marked divergence is noted at five years. This particular divergence, however, may be and probably is only a sampling fluctuation,[6] since it is noticeably out of line with the four and six year means, and no comparable marked increase at this age was found in the girls' sample, nor was it found by Christopher (28), Smedley (108), Hastings (57), Meredith (87), or Stewart (110).

Similarly it will be noted that the present means for girls are higher than those given by the other investigators, although the curves are practically parallel.

Possible reasons for the higher values found in the present study may be:

1. The smaller, lighter spirometer used offers less resistance to the entering air. The difference due to the use of the small spirometer was investigated by testing thirty-four Junior Primary children with the standard Narragansett spirometer after they had learned the technique of blowing with the small one. The mean breathing capacity registered on the large spirometer was 65.1 as compared with a mean of 66.7 for tests made the previous day with the small instrument. The difference was statistically significant at the 5 per cent level.
2. More time for learning the technique of taking the test was given in the present study, the scores being the second best of six days' trials rather than the best of three trials on one day. That this is probably the most important factor is shown by the fact that the mean scores for the first days' tests more closely approximate the mean scores given by the other investigators at all ages.
3. More time was spent in the present study in obtaining

[6] The average height of this group, 111.7 cm. is somewhat higher than usual for five-year-old boys in the preschool laboratories, as a result of the presence of several unusually tall boys.

and fostering the children's interest in the test. It is believed that the conditions necessary for obtaining maximum effort on the part of each child were better in the present study than in those with which comparison is being made.

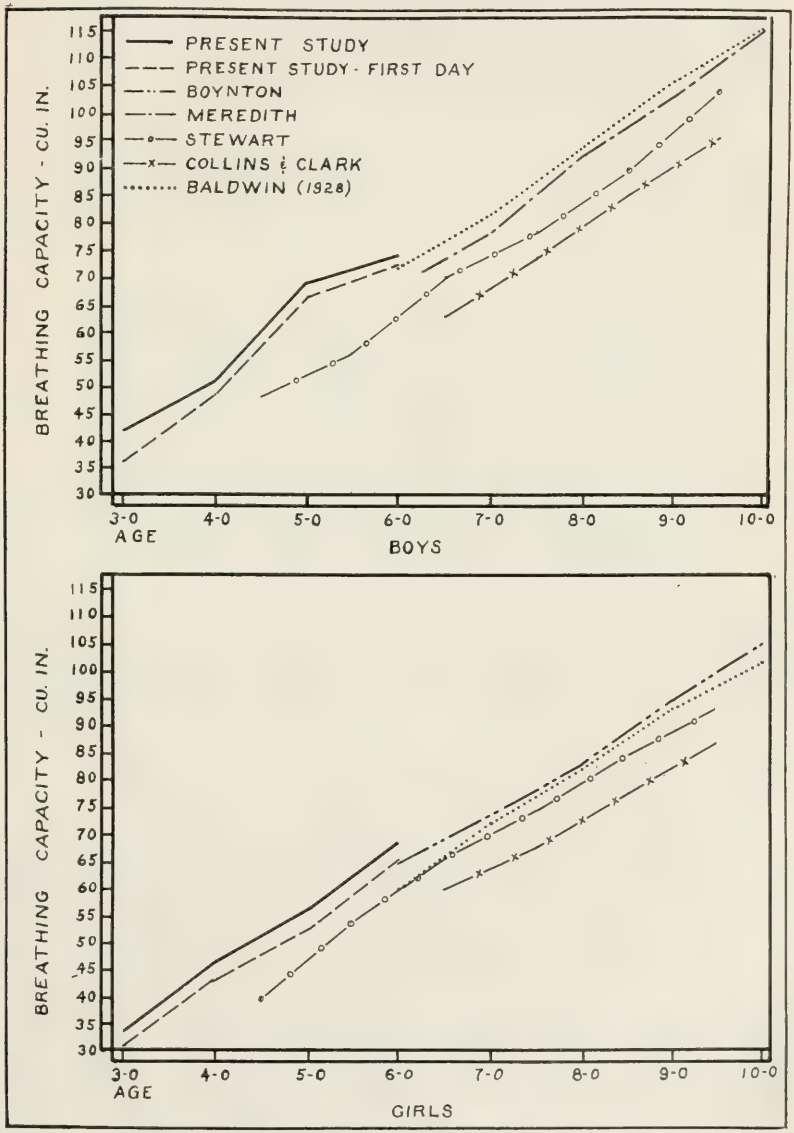

FIGURE 3. AGE MEANS FOR BREATHING CAPACITY.

After allowance is made for the consistently higher values found in the present study, the curves may be considered as being consistent in form with those given by Stewart (110) for this age period, and might be considered as a continuation downward of those given by Meredith (87) and Boynton (24) for older school children taken from the same Iowa private school population.

Meredith described the breathing capacity growth curves for boys as of a "three phase type." He wrote:

> "There is a relatively slow and constant growth (between six and twelve years), a period of rapid increase between about twelve and sixteen years, and a phase above sixteen years indicating a decline in growth rate." (87, p. 39)

A similar characterization was given by Stewart:

> "There appear . . . to be three main phases in the curve representing the increase in vital capacity for boys between 4 and 19 years: (1) a period of fairly uniform increase between 4 and 10; (2) a period of acceleration extending from 12 to 14; and (3) a period of uniform but less rapid increase in vital capacity to 19. . . . For girls . . . between 4 and 6 years of age the curve rises rather abruptly. From 7 to 10 the annual increase in vital capacity is fairly uniform but slower than during the earlier period. An acceleration in the rate of increase occurs at 11 and persists until 13." (110, p. 457)

The curves obtained in the present study seem to confirm the findings of Stewart as to a "fairly uniform increase between 4 and 10" for the preschool years, and may be used to extend Meredith's finding of "constant growth" between six and twelve years downward to three years.

SEX DIFFERENCES IN BREATHING CAPACITY

The existence of a sex difference in breathing capacity has been implied by every investigator who has reported means, correlations, or prediction equations for boys and girls separately.[7] General statements to the effect that boys exceed girls in breathing capacity at all ages have been made by Myers (90), Stewart (110), Smedley (108), Roberts and Crabtree (102), and Moersch (88). Baldwin

[7] Hutchinson's (64) comments on the breathing capacity of women in the year 1852 are interesting. He stated that he did not know whether or not his tables applied to women since it was impossible to measure their breathing capacity, owing to the tightness of their dresses. However, he believed the tables to be applicable since if women had equal weight for height, they would therefore need just as much oxygenation of the blood as would men.

(13) qualified this statement by saying that boys exceeded girls in breathing capacity except at the ages of thirteen and fourteen. Findings approaching those of Baldwin have been reported by Stewart (110), who stated that the breathing capacity of girls increased most rapidly from eleven to thirteen years; by Collins and Clark (29), who found the largest increments for girls at ages eleven and twelve with the result that the means for boys and girls were most nearly equal at thirteen years of age; and by Whipple (125), who stated that the most rapid increase in breathing capacity for girls came during the years from eleven to fourteen.

Descriptions of the growth curves of breathing capacity for the two sexes have been given by Baldwin (13) and Stewart (110). Baldwin wrote:

> "For the years 7 to 17, the curves tend toward concavity, which shows the increments increase less from 9 to 13 than during any other period for boys. . . . Among the girls some striking similarities to growth in height and weight may be noted in regard to the normal direction of lung capacity curves. . . . It is apparent that the girls' lung capacity curves show less concavity or decrease in absolute increment between 9 and 14 than the boys. This may be explained on the basis that the girls are becoming superior to the boys in height and weight during this period, only to drop back later in height, weight, and lung capacity. The lung capacity curves of the girls differ in their general trend from those of the boys and follow the same tendency as the weight curves of the girls." (Pp. 53-54)

Stewart's (110) description of the course of growth in breathing capacity for the two sexes from four to nineteen years has been previously quoted. (p. 48)

There seems to be little question of the fact that boys exceed girls in mean breathing capacity at all ages. This finding is borne out by the means of the present study shown in Table 4. At each age from three to six the mean breathing capacity for boys is greater than that for girls, and the differences in the means at each age are significant at the 1 to 2 per cent level. In this connection it must be appreciated, however, that boys are larger than girls at all ages from three to six, and, as will be shown in the following chapter, that breathing capacity is closely related to size. The question then arises: Is the difference in mean breathing capacity between boys and girls only a function of the difference in bodily size, or does there exist a sex difference larger than can be considered due to the difference in bodily size?

An approach to this problem has been made in the present study by the use of the method of analysis of covariance. By this technique the amount of the regression of one variable on another may be taken into consideration statistically and the means of the dependent variable "adjusted" to eliminate the influence of the independent variable. In this analysis height was selected as the independent variable to be held "constant" in the comparison. The mean height and breathing capacity of each age-sex group used in this analysis are shown below:

Age	Number	Height Cm.	Breathing* Capacity Cubic Inches
	Boys		
2 years, 6 months to 3 years, 5 months	18	98.8	42.1
3 years, 6 months to 4 years, 5 months	31	104.7	51.3
4 years, 6 months to 5 years, 5 months	39	111.8	69.0
5 years, 6 months to 6 years, 5 months	22	115.8	74.7
	Girls		
2 years, 6 months to 3 years, 5 months	22	95.1	33.9
3 years, 6 months to 4 years, 5 months	22	103.4	47.8
4 years, 6 months to 5 years, 5 months	25	108.4	55.4
5 years, 6 months to 6 years, 5 months	17	115.0	69.1

* These means differ slightly from those shown in Table 4, since only those children for whom height measurements were available could be included in the present analysis.

To investigate the differences from age to age, separate analyses were made for each age group, with the following results:

2 years, 6 months to 3 years, 5 months

Reduced Variance for Sexes	120.7186	1 d.f.
Reduced Variance Within Groups	35.4693	37 d.f.

$F = 3.44$, which is not significant. (At the 5 per cent level $F = 4.10$ for 1 x 37 d.f.)

3 years, 6 months to 4 years, 5 months

Reduced Variance for Sexes	149.0925	1 d.f.
Reduced Variance Within Groups	41.6059	50 d.f.

$F = 3.58$, which is not significant. (At the 5 per cent level $F = 4.03$ for 1 x 50 d.f.)

4 years, 6 months to
5 years, 5 months

Reduced Variance for Sexes	988.0513	1 d.f.
Reduced Variance Within Groups	66.9109	61 d.f.

F = 14.77, which is significant at the 1 per cent level for 1 x 61 d.f.

5 years, 6 months to
6 years, 5 months

Reduced Variance for Sexes	144.2128	1 d.f.
Reduced Variance Within Groups	86.3992	36 d.f.

F = 1.67, which is not significant for 1 x 36 d.f.

The results of these analyses are rather difficult to interpret. The difference between the adjusted means approaches significance at three years and four years, is clearly significant at five years, and is not significant at six years. In each instance, however, the adjusted means for boys are larger than the adjusted means for girls. Since the differences are all in the same direction, the probabilities may be combined to determine the significance of the differences for all four groups taken together. For the four age groups, the difference between the adjusted means is significant at the 1 per cent level. This would indicate that the breathing capacity of boys at these ages is greater than the breathing capacity of girls, even after due allowance has been made for the difference in height between the two sexes.

This finding was confirmed by a supplementary analysis for ages seven, eight, nine, and ten. Using the data given by Meredith (87) and Boynton (24) for the height and breathing capacity of boys and girls of these ages, an analysis similar to that described above was made. For these ages, the mean breathing capacity (adjusted for height) of boys was greater than the mean breathing capacity of girls. The difference was significant at the 5 per cent level.

GROWTH OF INDIVIDUALS

Thirty-seven children were tested in the spring of 1939 and again in the fall of the same year, from four- and one-half to seven months elapsing between the two sets of measurements. From these two sets of scores it was possible to compute individual increments in breathing capacity as an approach to the amount of individual variation in growth in this measure. Since there was some fluctuation in the length of time elapsing between tests, all increments were reduced to the amount gained (or lost) per month over the period. These monthly increments are tabulated below:

Age at First Test	Number	Mean Monthly Increment, Cubic Inches	Range
2 years, 6 months to 2 years, 11 months	1	1.25	
3 years, 0 months to 3 years, 5 months	8	1.55	—1.75 to 4.00
3 years, 6 months to 3 years, 11 months	7	.86	— .75 to 2.13
4 years, 0 months to 4 years, 5 months	11	1.63	.63 to 3.57
4 years, 6 months to 4 years, 11 months	7	1.69	.83 to 3.00
5 years, 0 months to 5 years, 5 months	3	.43	.14 to .71
Total	37	1.37	—1.75 to 4.00

It will be noted that the individual variation is great, the increments ranging from —1.75 to 4.00 cubic inches per month. (The negative increments probably represent only the failure of the experimenter to get the maximum possible score at the second testing.) Only three subjects showed losses, these being —.25, —.75, and —1.75 respectively, and all occurred with three-year-old children.

In connection with these individual changes Baldwin's statement concerning individual growth curves for breathing capacity is of interest:

> "As a rule, the greatest relative gains in breathing capacity occur between the first and second measurement, which is probably due to the fact that the child has learned how to use the spirometer, which involves a voluntary reaction as well as a physical measurement. . . . There is less uniformity in lung capacity than there is in weight. For example, between the ages of 7 ½ and 8 ½ the increment varies from a loss of 16 cu. cms. to an increase of 49. Before the age of 7 ½ there is absolutely no uniformity; after this the average may be roughly estimated at 8 to 16 cu. cm. increase." (13, p. 24)

The mean monthly increment of 1.37 cubic inches would suggest that the annual increment should be approximately 16.4 cubic inches. This is greater than the annual increases found in the cross sectional data (11.7 for girls and 10.7 for boys). Since the two tests were administered in the spring and the fall, this might be interpreted as indicating that greater increases in breathing capacity are made in the summer than in the winter.[8] On the other hand,

[8] Evidence concerning seasonal fluctuations in breathing capacity is con-

there may be a factor of experience entering into the second testing. A third possibility, of course, is that the phenomenon is simply a fluctuation due to sampling.

tradictory. Griffith, and others (53) tested five adult subjects weekly for a two year period and concluded: ". . . vital capacity (appears to have) no seasonal variation." (p. 575) Apperly (7) followed several subjects for a year and found that "Daily and general directions of vital capacity curves follow that of the temperature curve, swinging down in winter to rise again the following summer." (p. 295) Gould and Lockhart (52), however, found on comparing spring and fall measurements of breathing capacity of women students at Newcomb College that markedly larger gains were made during the winter than during the summer. They stated: "We must conclude then that there have been factors in the physical environment of the students during the winter that favor the gain in vital capacity—probably greater physical activity and more regular habits." (p. 42)

CHAPTER VII

RELATIONSHIP OF BREATHING CAPACITY TO CERTAIN PHYSICAL AND MENTAL MEASUREMENTS

ANTHROPOMETRIC RELATIONSHIPS

For children in the first decade of life, five studies have reported correlations of breathing capacity with other physical measurements. Two are by Baldwin (14, 15), one by Abernethy (1), one by Gates (48), and one by McCloy (78). Of these, Baldwin's report in 1921 is the most complete.

Baldwin analyzed the data obtained from repeated measurements of New York children at Horace Mann School, (ages 7 to 16). Using groups of approximately sixty children of each age and sex, he computed correlations of breathing capacity with height, weight, sitting height, chest circumference, grip strength, and strength of upper back, as well as a series of partial correlations showing interrelationships. His second study (15) in 1925 was made on the data gathered for Terman's *Genetic Studies of Genius,* and consisted of observations on 594 California children with IQ's of 130 or more, supplemented by data drawn from the Horace Mann School and from the schools of Oak Park, Illinois.

Gates' (48) work, published in 1924, was based on measurements of fifty-eight junior primary pupils (average age 5.7) and fifty-seven pupils in fourth grade (average age 9.6). He computed correlations specific for the four age-sex groups, but reported only the averages of these correlations. Abernethy's report (1) in 1936 dealt with measurements on 179 boys from the University of Chicago Laboratory School, ages eight to seventeen. Her correlations were computed for yearly increments in the measurements studied rather than for the original data. Correlations of annual increments in breathing capacity with increments for height, weight, sitting height, chest circumference, and measures of ossification of the wrist ranged from —.03 to .17. Since none of these was large enough to be significant, they will not be reported in detail.

McCloy's monograph (78), appearing in 1936, was based on measurements from the records of the Iowa Child Welfare Research Station.

The findings of these investigators are tabulated below:

Breathing Capacity With	Age, Years	Correlations		Boys and Girls
		Boys	Girls	
Height				
Baldwin (14)	7, 8, 9, 10	.763 to .817	.515 to .672	
McCloy (78)	10	.653	.697	
Gates (48)	5.7 and 9.6			.51
Weight				
Baldwin (14)	7, 8, 9, 10	.695 to .801	.434 to .643	
Gates (48)				.39
Chest circumference				
Baldwin (14)	7, 8, 9, 10	.621 to .768	.419 to .717	
Gates (48)				.59
Strength of grip				
Baldwin (14)	7, 8, 9, 10	.523 to .623	.379 to .694	
Baldwin (15)	9, 10	.339 to .514	.530 to .596	
Gates (48)				.46
Sitting height				
Baldwin (14)	7, 8, 9, 10	.690 to .843	.430 to .675	
Strength of upper back				
Baldwin (14)	7, 8, 9, 10	.394 to .563	.323 to .681	

Gates also reported correlations of .26 with nutrition (weight given in Baldwin-Wood tables minus actual weight), .21 and .31 with measures of ossification of the wrist, and —.01 with heart rate.

Somewhat more detailed attempts to analyze the relationships between breathing capacity and other physical measurements during the first decade of life have been made by Baldwin (13, 14, 16) and McCloy (78) using the partial and multiple correlation technique. The trend of Baldwin's correlations for the 1921 study is indicated in the tabulation given below. The measurement in parentheses is held statistically constant. The ages represented are 7, 8, 9, 10. From this analysis Baldwin concluded: "Growth in breathing capacity has a decided effect on the growth of the other traits except sitting height." (14, p. 139) From the nature of the variables involved it might be more reasonable to conclude that growth in the other traits is reflected in growth in breathing capacity.

Breathing Capacity With	Boys	Girls
Height (weight)	.351 to .528	.236 to .518
Height (sitting height)	—.044 to .446	—.072 to .461
Height (chest circumference)	.538 to .682	.256 to .591
Weight (height)	.069 to .351	.095 to .450
Weight (sitting height)	.196 to .345	—.007 to .546
Weight (chest circumference)	.375 to .496	—.003 to .271
Sitting height (height)	—.068 to .427	—.012 to .437
Sitting height (weight)	.267 to .527	.181 to .583
Chest circumference (height)	.177 to .465	.140 to .599
Chest circumference (weight)	.098 to .216	—.010 to .426
Grip (height)	.076 to .397	—.001 to .534
Grip (weight)	.068 to .274	.089 to .592

For the "genius" group, age seven to fifteen, Baldwin (15) reported correlations computed over the entire age range with age held constant. These correlations were:

Breathing Capacity With	Boys	Girls
Chest width (age)	.574	.495
Chest depth (age)	.483	.466
Chest circumference (age)	.600	.492
Right grip (age)	.934	.527

(It seems likely that the correlation of .934 between breathing capacity and grip with age held constant for boys is a typographical error, since the highest correlation reported for breathing capacity and grip strength for any one year of age is .694)

Baldwin (16) also reported correlations of breathing capacity with age, holding height constant by selecting a sample of 59 inch boys and 60 inch girls. For these groups the correlations are .24 and .35 respectively. Baldwin wrote: "These results indicate that age is not a negligible factor in establishing norms for breathing capacity. Height, however, is the more important of these two variable factors." (p. 258)

McCloy (78) reported a multiple correlation of .69 for breathing capacity with weight, height, chest circumference, shoulder width, hip width, and elbow width for ten-year-old boys. The correlation of breathing capacity with height and weight, however, is almost equally high, being .66. At twelve years the comparable values for the six variables were: .87 and for height and weight, .82; at fourteen years, .82 and .80; and from eighteen to twenty years .67 and .60.

For the second decade of life, correlational studies of breathing capacity and other physical measurements have been reported by Abernethy (1), Baldwin (14, 15), Binet and Vaschide (20), Jones (69), Louttit and Halford (76), MacCurdy (81), Van Dalen (120), McCloy (78), and Kelly (70). For college age students and adults similar investigations have been made by Alden and Top (3), Cripps, Greenwood, and Newbold (30), Gittings (51), Gould and Lockhart (52), Holzinger (63), Jackson (65), Jackson and Lees (66), Pasmore and Weymouth (93), Patrick and Rowles (94), and Turner (117, 118). No attempt will be made to describe the findings of these studies at this time, but specific reference will be made later to certain of them for comparative purposes. In general, the obtained correlations for the second decade of life run slightly higher than those for the first decade, while those for adults tend

to run somewhat lower. After an extended study of the available evidence relative to adults, Cripps, Greenwood and Newbold concluded:

> "Upon the evidence now available, it does not appear that either biometric or 'rational' formulae can deduce from the non-physiological or ordinary anthropometric constants, estimates of normal vital capacity confined within sufficiently narrow limits to possess real prognostic value in individual cases." (30, p. 336)

In the present study the relationship of breathing capacity to the following factors was studied:

Age
Stature
Weight
Chest circumference (xiphoid level)
Elbow width
Shoulder width (bi-acromial)
Sitting height
Hip width (bi-iliocristal)
Trunk length (suprasternale height—leg length)
Surface area (Benedict and Talbot (17) formula)
Arm length (acromiale to dactylion)

The age range included boys and girls from 2 years, 6 months through 6 years, 5 months; simple, partial, and multiple correlation methods were used. The measurements for each child were obtained within two months of the time of the breathing capacity tests. Some error in the obtained relationships is introduced by the fact that the time elapsing between anthropometric measurements and the breathing capacity test is not constant for all children. The general effect of this discrepancy, however, should be to decrease the size of the correlations obtained, and would only by chance make them spuriously high.

The small numbers of cases available for each specific age-sex group made it advisable to compute correlations for each sex over the entire age range to avoid chance fluctuations. For simplicity of computation, the few cases which did not have a complete set of measurements or which had not been tested for both grip strength and breathing capacity were discarded. The correlations were computed using 110 cases for boys and 79 cases for girls, ranging in age from 2 years, 6 months to 6 years, 5 months. For the trunk length measurement, data were available for only eighty-eight boys

Table 5

Correlations of Breathing Capacity and Grip Strength with Selected Anthropometric Measurements for Boys (N = 110) and Girls (N = 79), Ages 2 Years, 6 Months to 6 Years, 5 Months

Measurement	Mean	Standard Deviation	Grip Strength	Breathing Capacity	Age	Height	Chest Circumference	Elbow Width	Shoulder Width	Sitting Height	Forearm Girth
Boys											
Grip strength	10.99	2.48									
Breathing capacity	61.70	16.38	.796								
Age	4.48	.98	.743	.753							
Height	108.86	7.68	.802	.850	.782						
Chest circumference	54.56	2.84	.635	.740	.532	.735					
Elbow width	4.58	.35	.649	.631	.436	.706	.725				
Shoulder width	24.34	1.71	.776	.807	.713	.903	.821	.757			
Sitting height	61.65	3.54	.767	.827	.674	.949	.731	.736	.877		
Hip width	17.72	1.30	.756	.757	.626	.857	.744	.739	.871	.853	
Weight	41.98	6.92	.746	.760	.644	.912					
Upper arm girth	17.62	1.24	.321								
Forearm girth	17.59	1.08	.549								
Arm length (n=91)	45.91	3.49	.788			.939		.730			.655
Trunk length (n=88)	37.89	2.34		.760			.698				
Surface area (Benedict and Talbot) (17)	.80	.09		.777							
Mental age (Stanford-Binet) (n=103)	6.13	1.32	.562	.592	.791	.650					
Girls											
Grip strength	9.40	2.03									
Breathing capacity	51.80	14.87	.811								
Age	4.30	1.02	.792	.859							
Height	105.61	8.18	.851	.893	.881						

Chest circumference	52.53	2.81	.605	.697	.515	.685						
Elbow width	4.30	.24	.543	.592	.466	.605	.719					
Shoulder width	23.61	1.68	.847	.854	.774	.888	.768	.653				
Sitting height	59.79	3.76	.830	.845	.803	.954	.672	.590	.853			
Hip width	17.31	1.23	.775	.789	.738	.880	.713	.596	.818	.875		
Weight	39.53	6.61	.753	.788	.686	.860						
Upper arm girth	17.20	1.29	.325									
Forearm girth	17.78	.96	.470									
Arm length (n=60)	44.10	3.54	.862			.956						.507
Trunk length (n=59)	36.69	2.68		.725			.564					
Surface area	.74	.10	.771									
Mental age (Stanford-Binet) (n=66)	5.83	1.57	.708	.862	.895	.812						

and fifty-nine girls. In the case of arm length, ninety-one boys and sixty girls were used. The Pearson product-moment coefficients obtained are shown in Table 5.

For boys, the highest correlations were obtained with the measurements of length: height (.85), and sitting height (.83) were followed closely by shoulder width (.81). All correlations except that of breathing capacity and elbow width are above .75, indicating that the measurements of breathing capacity obtained are closely related to the gross size of the individual. However, the correlation with age is also of the magnitude .75, and the intercorrelations of the various measurements are in many cases greater than the correlations with breathing capacity.

For girls, the correlations are similar. Height (.89) and sitting height (.84) are high, but sitting height is slightly exceeded by age (.86) and shoulder width (.85). Chest circumference (.70) is slightly lower for girls than for boys (.74), but in general there are no very great differences between the two sexes.

Comparing these correlations with those given by Baldwin, McCloy, and Gates for children under ten years of age, it may be noted that those for preschool children are slightly higher for all measurements. But it must also be borne in mind that the preschool correlations are obtained over a four year age range, while those quoted for the school age are for single years.

A more detailed study of these relationships may be made using partial correlations. Those which were computed are shown in Table 6.

When age is held constant, the correlations of breathing capacity with all other measurements decrease to approximately .60 for boys and .55 for girls. The highest correlations for boys are with sitting height (.66), height (.64), and chest circumference (.61). For girls, the highest correlations with age held constant are with shoulder width (.59), chest circumference (.58), height (.57), and sitting height (.51).

When height is held constant the correlations of breathing capacity with other physical measurements decrease markedly for both sexes. For boys, the highest correlations with height constant are with chest circumference (.32) and age (.27). For girls the highest values are age (.35) and chest circumference (.27).

When the other measurements are held constant, the correlations between breathing capacity and height tend to decrease, but the

Table 6

Partial Correlations of Breathing Capacity with Selected Anthropometric Measurements for Boys and Girls, Ages 2 Years, 6 Months to 6 Years, 5 Months

Breathing Capacity and	Constant Variable							
	Age	Height	Chest Circum-ference	Shoulder Width	Sitting Height	Hip Width	Weight	Trunk Length
Boys								
Age		.270		.430			.531	
Height	.638		.672	.478	.366	.597	.590	
Chest circumference	.610	.324						.438
Elbow width	.511	.082						
Shoulder width	.586	.175						
Sitting height	.658	.124						
Hip width	.558	.107						
Weight	.546	—.073						
Trunk length			.505					
Girls								
Age		.348		.603			.712	
Height	.573		.819	.562	.542	.681	.685	
Chest circumference	.580	.266						.506
Elbow width	.424	.149						
Shoulder width	.585	.296						
Sitting height	.507	—.055						
Hip width	.448	.015						
Weight	.532	.088						
Trunk length			.561					

decreases are much less than when height is held constant to those measurements, indicating that the apparent relationships between breathing capacity and chest circumference, shoulder width, sitting height, hip width, trunk length, and weight are almost entirely due to the fact that all of the measurements show high correlations with height.

When age is held constant, the correlations obtained in the present study between breathing capacity and height, weight, chest circumference, and sitting height are higher than the average correlations given by Gates, but tend to be slightly lower than those given by Baldwin for one year intervals from seven to ten years for boys and girls.

To make further comparison possible, the correlation between breathing capacity and height was computed for each year of age from three to six for each sex. These correlations and the number of cases on which they are based are shown below:

Age	Boys		Girls	
	Number	r	Number	r
2 years, 6 months to 3 years, 5 months	21	.647	19	.629
3 years, 6 months to 4 years, 5 months	31	.618	22	.520
4 years, 6 months to 5 years, 5 months	39	.704	25	.586
5 years, 6 months to 6 years, 5 months	22	.747	17	.595

For the separate age groupings, as for the entire age range with age held constant, the correlations for boys tend to be slightly higher than those for girls. And again it may be noted that these correlations are higher than the average value of .51 given by Gates as the correlation between height and breathing capacity. The range of these correlations for boys is .62 to .75 and for girls is .52 to .63 as compared with ranges of .76 to .82 and .52 to .67 given by Baldwin for ages seven to ten.

Multiple correlations of breathing capacity with various combinations of physical measurements were computed as follows:

Breathing Capacity With	Boys	Girls
Age, height, chest circumference	.882	.930
Age, chest circumference	.853	.915
Height, chest	.867	.911
Height, age	.862	.907
Height, shoulders	.855	.903
Height, elbow		.892
Chest, trunk length	.814	.804

It will be seen that the addition of other variables slightly increases the correlations of height with breathing capacity which is .89 for girls and .85 for boys. In the following pages application of these multiple correlations to the estimation of the breathing capacity of individuals will be discussed.

ESTIMATES OF BREATHING CAPACITY FROM MEASUREMENTS OF BODY SIZE

Myers (90) has stated:

> "It is obvious that before any test can render its greatest service, reasonably accurate normal standards must be developed for comparative purposes. Because of wide individual variations, we know that individual standards observed in time of good health are best, but inasmuch as such standards are not available in most cases one is compelled to resort to theoretical normal standards." (p. 99)

Many formulae have been devised for estimating the "normal" or "expected" breathing capacity of a given individual. These formulae have been based on such measures of body size as height, weight, sitting height, chest circumference, surface area, and various combinations of these variables. Those relating to children of elementary school age are summarized below.

Estimates Based on Height

Hutchinson (64) believed that height was of importance in determining breathing capacity. He wrote:

> ". . . for every inch of stature from 5 ft. to 6 ft., eight additional cubic inches of air, at 60 F., are given out in one volume, by the deepest expiration immediately following the deepest inspiration." (p. 3)

Hastings (57) analyzed the relationship of height to breathing capacity at each age from five to twenty years for Nebraska school children. With approximately 500 observations for each age and sex, he arranged these data in height groups of 2, 3, or 4 cm. at each age, giving the mean breathing capacity for each height group. For example, for 565 eight-year-old boys, the height range was from 113 to 127 cm. The mean breathing capacity for the 113 to 114 cm. group was 54 cubic inches and for the 126 to 127 cm. group was 82 cubic inches, while the mean breathing capacity for all eight-year-old boys was 70 cubic inches. His careful analysis showed

clearly the great variability possible at a given age, and showed that breathing capacity tended to increase with height.

Edwards and Wilson (40) in 1922 assembled data on 360 "normal children" six to sixteen years of age, and plotted breathing capacity against height, weight, and surface area. They wrote:

> "An examination of these plots . . . reveals the greatest degree of scatter when the body weight is taken as the measure of relationship; also that there is little difference between relating the vital capacity to surface area and that relating it to height alone. . . . The method of relating the vital capacity to a body height measurement seems indicated as a general practical procedure." (p. 643)

But while they concluded that "the correlation of vital capacity and height is more intimate than that of vital capacity and surface area or body weight," they gave no standards based on height.

In the same year Stewart (110) reported means for breathing capacity based on height for boys from 98 to 188 cm. and girls from 98 to 173 cm., from observations of 1,289 male and 1,220 female "normal and healthy children." He gave regression equations for each height group, of which the following are representative:

Boys, 98 to 118 cm. B. C. = 25.1 (Ht. in cm.) —1622
Girls, 98 to 113 cm. B. C. = 25.5 (Ht. in cm.) —1744

In a later paper Stewart (111) predicted each child's expected breathing capacity from the appropriate formula and determined the per cent of deviation of the actual breathing capacity from the expected breathing capacity. Combining all ages and both sexes in one histogram, he obtained a close approximation of the normal probability curve, the range being from 65 per cent to 135 per cent. He concluded that a deviation of more than —8 per cent (one probable error) "places a child in a group representative of the inferior one-fourth of the child population in this respect." (p. 276)

Roberts and Crabtree (102) reported observations on 1,564 white and 1,254 negro children, six to eighteen years of age, in Tennessee. They stated that for white girls up to 140 cm. in height, each 5 cm. increase in height equalled 139 c.c. increase in breathing capacity; above 140 cm. each 5 cm. represented an increase of 194 c.c. For white boys up to 150 cm., each 5 cm. increase was matched by 167 c.c. increase in breathing capacity; above 150 cm. by 386 c.c.

Myers (90) prepared standards of breathing capacity for height

for the range of 57 to 76 inches for males and 55 to 74 inches for females. These tables were prepared "from the ratios given by West, Boynton, Shepard, Maeder, Cady and Myers." (p. 103) For children falling below this height range, he recommended the tables prepared by Stewart (110).

Kelly (70) arranged her breathing capacity data for boys and girls from twelve to eighteen years of age by one-inch height groups. She expressed the "best fit" relationship with the exponential equations:

$$\text{Boys: B. C. (cubic inches)} = .0002640 \text{ Ht. (in.)}^{3.25763}$$
$$\text{Girls: B. C. (cubic inches)} = .001529 \text{ Ht. (in.)}^{2.7957}$$

She also computed linear regression equations for the same data, but wrote:

> "The divergences favor a better fit of the parabola to the actual mean breathing capacities for the shorter boys; but for taller boys it fits no better and perhaps not as well as the straight line regression." (p. 18)

For girls: "The extreme height groups both upper and lower seem to be better fit by a parabola rather than a straight line." (p. 18)

For adults, standards based on height have been reported by West (124), Turner (117), Prudential Insurance Company of America (98), and Peabody and Wentworth (95), while Dreyer and Hanson (38) have stated that height is worthless as a standard for vital capacity.

Estimates Based on Weight

In 1921 Dreyer and Hanson (38) wrote:

> "It has been possible to show that definite relationships between the weight of the body, the length of the trunk (i.e., the height sitting), and the circumference of the chest do exist, as well as to demonstrate the uniformity of their relationship to the vital capacity of the lungs." (p. 2)

They described their subjects as "individuals of widely differing sizes and ages" (p. 2) the number of which is "sufficient to ensure a degree of accuracy that should prove entirely satisfactory." (p. 4) They expressed the relationship between weight and breathing capacity as:

$$\text{Males: Breathing Capacity} = \frac{\text{Weight, gm.,}^{.72}}{.69}$$

$$\text{Females: Breathing Capacity} = \frac{\text{Weight, gm.,}^{.72}}{.79348}$$

and gave tables for calculating these values. They further subdivided their subjects into classes A, B, and C on the basis of their mode of life, and gave separate standards for each group. The lower limit of the age range to which these standards are applicable is not stated, but examples of children as young as eight years are cited.

Stewart (110) also grouped his data by weight and gave regression equations for determining breathing capacity from weight for the range of 33 to 153 pounds for males and 38 to 138 pounds for females. For the lightest children his regression equations are:

Boys: Weight 33 to 48 lbs. B. C. = 22.0 (Weight) + 263
Girls: Weight 38 to 63 lbs. B. C. = 29.0 (Weight) — 172

Myers (90) also gave tables for breathing capacity based on weight, but failed to indicate how they were compiled. The weight range for these tables is 80 to 200 pounds.

Kelly (70) analyzed her data in terms of weight, and fitted exponential equations:

Boys: B. C., cu. in. = 1.8208 (Weight, pounds)$^{1.004855}$
Girls: B. C., cu. in. = 7.1947 (Weight, pounds)$^{.6564}$

For women of college age, Turner (118) prepared norms for breathing capacity based on weight.

Estimates Based on Sitting Height

Sitting height has been used as the basis of norms by Dreyer and Hanson (38), Myers (90), Roberts and Crabtree (102), and Stewart (110).

Dreyer and Hanson gave the formulae:

$$\text{Males: Breathing Capacity} = \frac{\text{Sitting Height, cm.}^{2.257}}{6.1172}$$

$$\text{Females: Breathing Capacity} = \frac{\text{Sitting Height, cm.}^{2.3003}}{8.2714}$$

Myers used Dreyer's formulae as the basis for the sitting height tables given in his book.

Roberts and Crabtree found that for white girls whose sitting height was less than 85 cm., breathing capacity increased 151 c.c. for each two cm. growth in sitting height; for white boys, 171 c.c. per 2 cm. growth in sitting height up to 79 cm. and 253 c.c. per 2 cm. from 79 to 85 cm.

Stewart gave regression equations for sitting height groups. For the shortest children the regressions were:

Boys: 53 to 61 cm. Breathing Capacity = 41.5 (Sitting Height, cm.) —1224
Girls: 51 to 61 cm. Breathing Capacity = 48.6 (Sitting Height, cm.) —1728

Estimates Based on Chest Circumference

Dreyer and Hanson (38) discussed the relationship between chest circumference (taken at the nipple level in males, just below the breasts in females, while the subject is breathing normally) and vital capacity. They derived the formulae:

$$\text{Males: Breathing Capacity} = \frac{\text{Chest Circumference, cm.}^{1.973}}{1.5595}$$

$$\text{Females: Breathing Capacity} = \frac{\text{Chest Circumference, cm.}^{2.5352}}{16.4951}$$

Myers (90) based his tables on these formulae.

Estimates Based on Surface Area

The relationship existing between oxygen intake and metabolism has led a number of workers to investigate the possibility of setting up standards of breathing capacity based on the surface area of the body. Formulae for calculating the sufrace area of the body have been presented by DuBois and DuBois (39), and by Benedict and Talbot (17). Edwards and Wilson (40) compared the results from the two methods on ten cases, and reported that the former gave values about 12 per cent higher than the latter. The DuBois and DuBois formula has not been validated for preschool age children. The Benedict and Talbot formula is applicable to children weighing from 10 to 40 kg.

Emerson and Green (42) reported that a "very close relationship was found between vital capacity and surface area in children." (p. 211) They used the Benedict and Talbot formula for most of their cases, but applied the DuBois and DuBois formula to their older subjects. Their data were gathered on 266 boys and 88 girls, seven to fifteen years, assembled from the outpatients at children's hospitals, boys clubs, orphanages, and settlements. Their data, however, do not bear out their conclusion.

Height, Centimeters	Number	Average Breathing Capacity, Liters	Surface Area	Ratio
		Boys		
63 to 69.8	12	1.8	1.5	1.2
57 to 63	66	1.4	1.3	1.1
51 to 57	144	1.1	1.1	1.0
46 to 51	44	.8	1.0	.8
		Girls		
53 to 59.5	34	1.1	1.2	.9
47 to 53	36	.8	.9	.7
43 to 47	14	.7	.9	.6

Since their ratios show a range of .6 to 1.2, the largest being twice the smallest, there would seem to be no very close relationship between breathing capacity and surface area in their data.

Edwards and Wilson studied the surface-area/breathing capacity relationship in three papers (126, 40, 41). Their first study (126) was based on 85 subjects, six to sixteen years, who were "in apparent good health and were regularly attending public school." (p. 445) Breathing capacity was measured in the sitting posture, and the DuBois and DuBois formula was used for determining surface area. They expressed their results in terms of liters/sq. m., finding for boys an average of 1.90 and for girls 1.84. Using as their norm 1.87 liters/sq. m. for both sexes, they found that 67 per cent fell within a 10 per cent deviation. They attempted to arrange their data by 3 inch height groups, but "the great degree of variability exhibited by the figures obtained made it evident that such a method possessed no practical value." (p. 447) They observed a few subjects five to eight years of age with a surface area less than .85 sq. m. "In these we have obtained a consistently low vital capacity." (p. 447)

In 1922 (40) they studied 360 normal children, six to sixteen years, and concluded "that there is little difference between relating the vital capacity to surface area and that relating it to height alone." (p. 643) They analyzed their data in .10 sq. m. surface area groups, and found a range of from 1.74 liters for surface area of .70 to .79 sq. m. to 2.18 liters for 1.80 to 1.89 sq. m. They found the standard deviation of the distribution of liters/sq. m. to be .27 for 360 cases, and concluded:

> "In the evaluation of an individual vital capacity measurement on the basis of surface area some account has to be taken of the actual size of the subject measured before an accurate

> estimate of the deviation from the normal can be made.'' (p. 645)

In 1939 (41) they added eighty cases to their original data and revised their breathing capacity/surface area standard in terms of size. They presented a table showing breathing capacity/sq. m. surface area for each .10 sq. m. from .60 to 2.20, and supplemented this with a chart showing ''normal'' breathing capacity for surface area, with supplementary lines showing deviations from 10 per cent to 40 per cent.

Kelly (70) computed the surface area values for her data on boys from DuBois and DuBois' formula and expressed the relationship between surface area and breathing capacity by the exponential equation:

$$\text{Breathing Capacity, Cubic Inches} = 108.10\ \text{S.A.}^{1.51601}$$

She concluded that considering the

> ''possible errors in the use of a formula that has not been statistically established for the age range of these data, it was considered the better procedure to compute norms for breathing capacity in terms of height and weight rather than surface area.'' (p. 34)

Surface area-breathing capacity studies of adults have been reported by Peabody and Wentworth (95), West (124), Lemon and Moersch (75), and Turner (118).

Estimates Based on More Than One Variable

In 1922, Stewart and Sheets (113) published tables for breathing capacity in metric units determined from age and height, specific for each sex. These data were derived from the measurements of 2,400 Minneapolis school children, five to eighteen years old. In the same year, Stewart (110) published a similar table, but with slightly different values. Stewart's publication also includes tables of breathing capacity for sex, age, and sitting height.

Baldwin (16) in 1928 assembled all of his breathing capacity data from various sources and compiled age-height tables for breathing capacity in English and metric units for each sex, ages six to nineteen years, based on 22,913 measurements of boys, and 10,737 measurements of girls. The average standard deviation of the age-height-sex distributions was 13 per cent of the mean breathing capacity score. Baldwin's values tend to run about 5 cubic inches

lower than those given by Stewart and Sheets. The values given by Baldwin and by Stewart and Sheets have been smoothed and rounded. Those given by Stewart are apparently the observed means.

After careful analysis of the variables involved, Kelly (70) concluded that age, height, and weight were the most satisfactory combination of variables from which to estimate "expected" breathing capacity for the ages twelve to eighteen. She presented tables in which expected breathing capacity in cubic inches may be read directly given an individual's weight in pounds, age in years, and height in inches. The tables for boys are derived from the regression equation:

$$\text{Breathing Capacity} = .000381\ \text{Ht.}^3 + .767587\ \text{Wt.} + 5.953352\ \text{Age} - 71.959$$

Separate regression equations for each year of age were used for the girls' tables. For twelve-year-old girls the equation was:

$$\text{Breathing Capacity} = 3.240\ \text{Ht.} + .378\ \text{Wt.} - 90.840$$

The use of these norms was recommended by McCloy (79) with the suggestion that when possible "normal" weight should be used in preference to actual weight.

Dreyer and Hanson (38) compiled tables separately for each of the variables, sitting height, chest circumference, and weight, but recommended their combined use, stating that all three must be considered in arriving at "normal" breathing capacity. Myers (90) likewise felt that a combined use of the tables was more desirable than dependence on any one table, and recommended that the tables based on surface area, weight and standing height should all be used in arriving at an estimate of the "normal" breathing capacity of an individual.

The Applicability of Available Formulae to the Present Data

An interesting comparison may be made among these divers formulae by applying them to the data of the present study. Particularly those presented by Dreyer and Hanson (38), Kelly (70), Stewart (110), and Edwards and Wilson (41) lend themselves to this type of comparison. It must be remembered that in every instance the use of these formulae involves extrapolation, since none of them were derived from observations on preschool children. Dreyer and Hanson's subjects were not described as to age, but they applied the formulae with children as young as eight years.

Kelly's subjects were twelve to eighteen years of age. Stewart's subjects were school children, only a few of whom were as young as five years. Edwards and Wilson used children from six to sixteen years of age, but reported poor success with younger children.

In the following tabulation are shown the results of substituting the mean measurements for boys and girls of the present study in the formulae previously quoted. The measurements used were:

	Boys	Girls
Age, years	4.5	4.3
Height, cm.	108.9	105.6
Weight, pounds	42.0	39.5
Sitting height, cm.	61.6	59.8
Sitting height, cm.	61.6	59.8
Surface area, square m.	.80	.74
Breathing capacity, cubic inches	61.7	51.8

The results obtained for breathing capacity in cubic inches were:

	Boys	Girls
Estimates based on height		
Stewart (110)	67.8	58.1
Kelly (70)	57.4	53.5
Estimates based on weight		
Dreyer and Hanson (38)	106.8	92.4
Stewart (110)	72.6	59.5
Kelly (70)	77.9	80.4
Estimates based on sitting height		
Dreyer and Hanson (38)	109.1	90.1
Stewart (110)	77.6	71.8
Estimates based on chest circumference		
Dreyer and Hanson (38)	104.7	84.5
Estimates based on surface area		
Kelly (70)	77.0	
Edwards and Wilson (41)	88.0	75.0

The range of breathing capacity estimates for boys is from 57.4 to 109.1 cubic inches, and for girls from 53.5 to 92.4 cubic inches. The values given by Kelly's height formulae, 57.4 for boys and 53.5 for girls and by Stewart's height formulae, 67.8 and 58.1, most nearly approach the actual values found for breathing capacity, 61.7 for boys and 51.8 for girls. The values derived from the other formulae of Stewart and Kelly, and from the formulae of Dreyer and Hanson, and Edwards and Wilson, are all higher than the observed means.

Possible explanations of these differences may be made in terms of several factors. (1) It may be that age, as such, is a real factor in determining breathing capacity, so that an older child may have a greater breathing capacity than a younger child of the same body size and form. (2) Since bodily proportions change from age to

age, it may be that the relationship of breathing capacity to composite measures, such as height, undergoes similar changes. (3) A third hypothesis may be that the formulae given fit the data from which they were derived more closely at the means than at the extremes. In that case, attempting to extend the regression lines or exponential curves downward would exaggerate the divergences of the curves from the actual values.

Whatever the explanation of the differences may be, it seems reasonable to conclude that none of the formulae available at present would be satisfactory for use with preschool children.

Prediction Tables for Preschool Children

In the correlational analysis of breathing capacity and anthropometric measurements it was found that height was the best single variable from which to estimate breathing capacity at these ages. The correlation between height and breathing capacity was .89 for girls and .85 for boys. The addition of other variables served to raise these correlations slightly, height and age giving .91 for girls and .86 for boys, while age, height, and chest circumference gave .93 for girls and .88 for boys.

If prediction tables are to be useful in any practical school situation, at least two major considerations must be kept in mind in building them. (1) They must be as accurate as possible; and (2) they must be reasonably easy to administer. The first consideration would lead to the choice of the combination of age, height, and chest circumference as the basis for predicting breathing capacity; the second would lead to the choice of a single variable, preferably one such as age which could be determined from the school records. A compromise may be made between them by selecting two easily obtained measurements which have a high correlation with breathing capacity.

The two measurements selected after a study of the correlations were height and age. Their multiple correlation with breathing capacity is not as high as height and chest circumference (.91 for girls and .87 for boys) or as high as age, height and chest circumference (.93 and .88 respectively), but both may be obtained easily in any school situation. To obtain an accurate determination of chest circumference requires that the child be undressed, and facilities for taking nude measurements are not always available.

The multiple correlations of height and age with breathing

capacity are only slightly higher than those of height alone, but age may be determined so easily that it was considered worth adding for whatever slight predictive value it might have. The increase in predictive accuracy due to the addition of the age variable will be greatest for those children who are at the extremes of the range of height for their age.

From the intercorrelations of breathing capacity, height, and age, the following regression equations were determined:

Boys: Breathing Capacity, Cubic Inches = 1.4331 (Ht., cm.) + 3.8133 (age) — 111.3903 (R = .85)
Girls: Breathing Capacity, Cubic Inches = 1.1023 (Ht., cm.) + 4.7294 (age) — 84.9755 (R = .91)

The standard error of estimate is 4.42 cubic inches for the boys' equation and 2.92 cubic inches for the girls. Since the mean for boys is 61.70 cubic inches and for the girls 51.80 cubic inches, the standard error of estimate for boys is about 7 per cent of the mean, and for girls about 6 per cent of the mean.

From these regression equations Table 7 was computed for the prediction of breathing capacity of preschool children between the ages of 2 years, 6 months and 6 years, 5 months.

In using these tables, age is taken to the last half year. Thus, if a boy were 3 years, 4 months of age, his breathing capacity would be found in the column for 3 years, 0 months to 3 years, 5 months. If he were 102 cm. tall, his estimated breathing capacity would then be 42 cubic inches. If a boy were 3 years, 11 months of age, his breathing capacity would be found in the column for 3 years, 6 months to 3 years, 11 months. If his height were 111 cm., his estimated breathing capacity would be 54 cubic inches.

The values given in Table 7 for five- and six-year-old children may be compared with those given by Stewart and Sheets (113) for five- and six-year-old children in their age-height-breathing capacity tables, and with those given by Baldwin (16) for six-year-old children. The values for boys and girls follow:

Boys

Investigator	Height, Centimeters									
	98	103	108	110	112.5	113	115	117.5	118	123
Stewart and Sheets (113)										
5 years, 0 months to 5 years, 11 months	40	46	53			60				
Present study										
5 years, 0 months to 5 years, 5 months	48	55	62			70				
5 years, 6 months to 5 years, 11 months	50	57	64			72				
Stewart and Sheets (113)										
6 years, 0 months to 6 years, 11 months		49	58			67			74	81
Baldwin (16)										
6 years, 0 months to 6 years, 11 months				60	70		70	75		
Present study										
6 years, 0 months to 6 years, 5 months		59	66	69	72	73	76	80	82	88

Girls

Investigator	Height, Centimeters										
	88	93	98	103	109	110	112.5	113	115	117.5	118
Stewart and Sheets (113)											
5 years, 0 months to 5 years, 11 months	37	40	43	50							
Present study											
5 years, 0 months to 5 years, 5 months	36	42	47	52							
5 years, 6 months to 5 years, 11 months	38	44	49	55							
Stewart and Sheets (113)											
6 years, 0 months to 6 years, 11 months			49	52	56			64			67
Baldwin (16)											
6 years, 0 months to 6 years, 11 months						55	65		65	70	
Present study											
6 years, 0 months to 6 years, 5 months			51	57	62	65	67	68	70	72	73

Table 7

Estimates of Breathing Capacity in Cubic Inches from Age to the Last Half Year and Height in Centimeters for Boys and Girls*

Height, Centimeters	Age							
	2 Years, 6 Months to 2 Years, 11 Months	3 Years, 0 Months to 3 Years, 5 Months	3 Years, 6 Months to 3 Years, 11 Months	4 Years, 0 Months to 4 Years, 5 Months	4 Years, 6 Months to 4 Years, 11 Months	5 Years, 0 Months to 5 Years, 5 Months	5 Years, 6 Months to 5 Years, 11 Months	6 Years, 0 Months to 6 Years, 5 Months
	Boys							
90	27	29	31					
91	29	30	32					
92	30	32	34					
93	31	33	35	37				
94	33	35	37	39				
95	34	36	38	40				
96	36	38	40	41				
97	37	39	41	43	45			
98	39	40	42	44	46			
99	40	42	44	46	48			
100	41	43	45	47	49	51		
101	43	45	47	49	51	52		
102	44	46	48	50	52	54		
103	46	48	50	51	53	55		
104	47	49	51	53	55	57		
105	49	51	52	54	56	58	60	62
106	50	52	54	56	58	60	61	63
107	51	53	55	57	59	61	63	65
108		55	57	59	61	62	64	66
109		56	58	60	62	64	66	68
110		58	60	62	63	65	67	69
111		59	61	63	65	67	69	71

* For boys, breathing capacity = 1.4331 Height + 3.8133 Age — 111.3903
For girls, breathing capacity = 1.1023 Height + 4.7294 Age — 84.9755

112		61	62	64	66	68	70	72
113			64	66	68	70	72	73
114			65	67	69	71	73	75
115			67	69	71	72	74	76
116			68	70	72	74	76	78
117				72	73	75	77	79
118				73	75	77	79	81
119				74	76	78	80	82
120				76	78	80	82	83
121				77	79	81	83	85
122					81	83	84	86
123					82	84	86	88
124					83	85	87	89
				Girls				
85	21	23						
86	22	24						
87	23	25						
88	24	26						
89	25	27						
90	26	28	31					
91	27	30	32					
92	28	31	33					
93	29	32	34					
94	30	33	35					
95	32	34	36	39				
96	33	35	37	40				
97	34	36	39	41				
98	35	37	40	42	44			
99	36	38	41	43	45			
100	37	39	42	44	47	49		
101	38	41	43	45	48	50		
102	39	42	44	46	49	51		
103	40	43	45	47	50	52	55	
104	41	44	46	49	51	53	56	58

Height, Centimeters	Age							
	2 Years, 6 Months to 2 Years, 11 Months	3 Years, 0 Months to 3 Years, 5 Months	3 Years, 6 Months to 3 Years, 11 Months	4 Years, 0 Months to 4 Years, 5 Months	4 Years, 6 Months to 4 Years, 11 Months	5 Years, 0 Months to 5 Years, 5 Months	5 Years, 6 Months to 5 Years, 11 Months	6 Years, 0 Months to 6 Years, 5 Months
105	43	45	47	50	52	54	57	59
106	44	46	48	51	53	56	58	60
107	45	47	50	52	54	57	59	61
108	46	48	51	53	55	58	60	62
109	47	49	52	54	56	59	61	64
110	48	50	53	55	58	60	62	65
111	49	52	54	56	59	61	63	66
112	50	53	55	57	60	62	64	67
113		54	56	59	61	63	66	68
114			57	60	62	64	67	69
115			58	61	63	65	68	70
116			59	62	64	67	69	71
117			61	63	65	68	70	72
118				64	66	69	71	73
119				65	67	70	72	75
120				66	69	71	73	76
121				67	70	72	74	77
122					71	73	76	78
123					72	74	77	79
124					73	75	78	80
125					74	76	79	81

It will be seen that the values obtained in the present study tend to be somewhat higher than those given by Stewart and Sheets or by Baldwin. The differences seem to be more marked for boys than for girls, although there is no apparent reason for this difference between the sexes. On the whole, however, the three sets of tables may be said to follow the same pattern and to be roughly comparable.

The Breathing Capacity Quotient

From the values given in Table 7 the expected breathing capacity for age and height was determined for each of the subjects used in the present study. The actual breathing capacity multiplied by 100 was divided by the expected breathing capacity to give a score termed the Breathing Capacity Quotient (BCQ). The range of these breathing capacity quotients was from 70 to 141. The standard deviation of the entire distribution was 13.4. Frequency distributions of the quotients for separate age-sex groups are shown in Table 8.

Baldwin (16) found the average standard deviation of the age-height-sex distributions of 22,913 breathing capacity measurements for boys and 10,737 measurements for girls from six to nineteen years to be 13 per cent of the mean score. He stated: "A child whose breathing capacity deviates 13% from the average breathing capacity for his height and age does not have a normal breathing capacity on a statistical basis." (p. 258) The standard deviations of 13.4 per cent found in the present study and 13 per cent found by Baldwin are comparable to the probable error of 8 per cent given by Stewart (111) for deviations of actual breathing capacity from breathing capacity estimated from height.

The subjects in the present study were all healthy, presumably normal children, who were at least well enough to be in regular attendance at preschool. They were a selected group with regard to socio-economic status. For this group the distribution of breathing capacity quotients is essentially normal in form, and the range may be described in terms of the standard deviation of the distribution. For one standard deviation on either side of the mean the range is 87.3 to 114.1, for two standard deviations, 73.9 to 127.5, and for three standard deviations, 60.5 to 140.9. No child lies more than three standard deviations from the mean in either direction. Only two children lie more than two standard deviations above the mean, and seven more than two standard deviations below it.

Table 8
Distribution of 202 Breathing Capacity Quotients for Children 2 Years, 6 Months to 6 Years, 5 Months

Breathing Capacity Quotients	Age								
	2 Years, 6 Months to 3 Years, 5 Months		3 Years, 6 Months to 4 Years, 5 Months		4 Years, 6 Months to 5 Years, 5 Months		5 Years, 6 Months to 6 Years, 5 Months		2 Years, 6 Months to 6 Years, 5 Months
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	All Cases*
140 to 144	1								1
135 to 139					1				1
125 to 129	2	1	1			1			5
120 to 124	1	3			2		2	1	9
115 to 119	1			3	4	1	3	1	13
110 to 114		2	2	3	4	1	2	3	17
105 to 109	3	1	4	3	7	3	2	1	24
100 to 104	3	5	5	6	9	9	2	4	43
95 to 99	1	1	3	1	3	2	6	5	22
90 to 94	2	5	6	4	3	3	3	1	27
85 to 89	1		4	1	2	1	2		11
80 to 84	1	1	4	1	4	2	1	1	15
75 to 79	3				2	1	1		7
70 to 74		2				2	2	1	7

* Mean = 100.7; S.D. = 13.4

What the distribution of breathing capacity quotients would be for a sample selected at random from the total population has not been determined.

MENTAL RELATIONSHIPS

The literature on the relationship of breathing capacity to mental ability is somewhat confusing. As early as 1897 Gilbert (50) studied the breathing capacity of children from ten to fifteen years of age and reported that the duller children (as rated by teachers) had the larger breathing capacity. Christopher (28) in 1900, and Smedley (108) in 1901 contradicted this finding. They used eleven- and twelve-year-old children classified according to school grade, and found that those in the higher grades had larger breathing capacities than those in the lower. Smedley from an analysis of data for inmates of the John Worthy School (a house of correction) concluded: "These pupils are found to be inferior in all the principal measurements taken [including breathing capacity], and this inferiority seems to increase with age." (108, p. 89)

DeBusk (32, 33) in 1913 and again in 1917 compared breathing capacities of "retarded" children with "normal" and "accelerated" children, (as determined by school grade) and stated: (a) "Regardless of age the accelerated show a relatively high vital index while the retarded are relatively low." (33, p. 12) and (b) "Almost without exception, when compared with normal or accelerated children of their own age, the retarded show a vital capacity under the average." (32, p. 90)

In 1914, Baldwin (16) wrote:

> "That there is a possible correlation between school standing and lung capacity is indicated by the fact that, if the 5 boys or 5 girls with the greatest lung capacity are selected, the average school marks for these are invariably above the average school marks of any 5 with the lowest average lung capacity. This holds true for each group, but it is not, however, a complete or accurate test, since all cases are not included and the grades and lung capacity are both materially influenced by the age of the boy or girl." (p. 91)

However, the "geniuses" studied by Baldwin (15) showed no marked superiority over average children in breathing capacity.

Berry and Porteus (18) reported correlations between vital capacity and Binet mental age (894 cases) and Porteus mental age (1,248 cases) for children between the ages of six and thirteen.

They analyzed their data in one-year-age groupings. With Binet mental age the correlations ranged from negative values (not given) to .50, and with Porteus mental age from negative values to .62. They concluded: "... on the whole, there is a positive relation between psycho-physical measurements [including breathing capacity] and the results of mental tests."

Garrison and Pullias (47) tested forty-five children in grades four to eight in the demonstration school of George Peabody College. Ranking the groups by percentiles of a random population "using appropriate percentile tables," they found that all of the IQ's were in the 90th percentile and the breathing capacities in the 60th to the 90th percentiles. Their failure to identify the percentile tables employed makes it difficult to evaluate their results.

Gates (48) compared the breathing capacities of kindergarten and fourth grade children (previously described) with Stanford-Binet mental ages and teachers' ratings of mental maturity, social maturity, scholastic maturity, and emotional maturity. The correlations ranged from .06 to .12. He wrote: "Among the pupils of Horace Mann School . . . physical superiority, particularly vigor and stamina, effect a positive but nevertheless slight influence upon achievement." (p. 348)

Abernethy (1) found correlations of from —.04 to .27 between breathing capacity and Stanford-Binet test scores for boys eight to seventeen years of age. The correlations were computed separately for each year of age. Using yearly increments, the correlations ranged from —.11 to .25. However, she concluded: "There is rather convincing evidence of a slight positive relationship between mental-test scores and each of the measures of physical growth [including breathing capacity]." (p. 12)

Studies on the older school ages and on adults by Jones (69), Holzinger (63), Gittings (51), Patrick and Rowles (94), Stalnaker (109), and McKinstry (85) have shown uniformly low relationships, both positive and negative, between breathing capacity scores and measures of mental ability. From them the only conclusion which may be drawn is that if there is any relationship between breathing capacity and mental ability, it is very slight.

For the subjects used in the present study intelligence test data were available for 103 boys and 66 girls. These data consisted of scores made on the 1937 Revision of the Stanford-Binet Intelligence Test given within a period of two months from the date of the

breathing capacity test. The approximate mental age at the time of the breathing capacity test was computed by multiplying the intelligence quotient at the time of the mental test by the chronological age in months at the time of the breathing capacity test.

Over the entire age range (2 years, 6 months to 6 years, 5 months) the correlation between mental age and breathing capacity was .59 for boys and .86 for girls. These values may be compared with the correlations obtained between breathing capacity and chronological age, .75 for boys and .86 for girls. When chronological age is held constant, the correlations between mental age and breathing capacity become insignificant, dropping to zero for boys and .41 for girls.

A similar drop in the relationship between mental age and breathing capacity is found when height is held constant. The correlations are .10 for boys and .52 for girls. However, the multiple correlation of breathing capacity with mental age and height is .85 for boys and .92 for girls. For boys this value is slightly lower than the correlation of breathing capacity with height and chronological age (.86), for girls slightly higher than the same multiple correlation (.91). In neither instance, however, are the differences great enough to indicate any marked superiority for either variable in estimating the breathing capacity of a given individual.

A comparison was also made between intelligence quotients and the breathing capacity quotients for the two sexes combined. The correlation obtained, .18, indicates that these two quotients have no significant relationship.

However, it is possible with preschool age children that intelligence does play a part in determining the ease with which they master the technique of blowing. For the subjects of the present study the IQ range was from 85 to 191, with a mean of 129.5 and a standard deviation of 16.5. Only one child had an IQ below 100. It is recognized that these children constitute a superior group mentally, and that somewhat different results might have been obtained with subjects from the lower mental levels.

CHAPTER VIII

SUMMARY

In the preceding chapters a number of problems related to the breathing capacity of preschool children have been investigated. The problems have included such diverse areas as the construction of a spirometer, administration of the test, reliability and variability, determination of group means, physical and mental relationships, sex differences, and individual growth. Before proceeding to a discussion of the health implications of breathing capacity tests, it may be helpful to list the principal findings of this exploratory section.

A spirometer suited to the size, ability, and interest of preschool children was constructed. Procedures for administering the test of breathing capacity to preschool children were evaluated. (1) Individual testing was found preferable to testing in groups. (2) The time of day at which the test was given had no significant effect on the scores. (3) Five trials appeared to be the optimum number to be given at one testing. (4) The second best of the scores made in six days of testing was selected as the final score to be used for each individual.

Following the standardized procedure, the test was administered to 206 preschool children between the ages of 2 years, 6 months and 6 years, 5 months.

The reliability of the test scores was investigated by comparing the best score made on the odd days with the best score made on the even days from six days of testing. Correlations of approximately .90 were obtained for the separate age-sex groups.

Age means for breathing capacity were determined for boys and girls from three to six years of age. These means are higher than any previously reported at these ages, but are consistent with comparable means for the older ages.

An analysis of the coefficients of variation indicated that the breathing capacity of preschool children is no more variable than that of children between six and eighteen years of age.

Boys were found to have greater breathing capacities than girls at all ages from three to six. When the effect of differences in height

was eliminated, the boys still exceeded the girls in breathing capacity.

Data on individual growth in breathing capacity were presented for those children tested in the spring and again in the fall.

The relationship of breathing capacity to thirteen anthropometric measurements was studied. Height yielded the highest correlation with breathing capacity. Partial and multiple correlational analyses confirmed the finding that height is the best indicator of breathing capacity at this age level.

No relationship was found between breathing capacity quotients and intelligence quotients as determined by the 1937 Revision of the Stanford-Binet Intelligence Test.

Tables for estimating the breathing capacity of an individual from height and age were prepared. Actual breathing capacity multiplied by 100 and divided by expected breathing capacity from these tables was termed the Breathing Capacity Quotient (BCQ).

The pertinent research on children in the first decade of life was reviewed under each of the topics treated, and comparisons were drawn between the findings of the present study and findings of other investigators.

Section III

GRIP STRENGTH

CHAPTER IX

PREVIOUS STUDIES OF THE GRIP STRENGTH OF PRESCHOOL AGE CHILDREN

This discussion is limited to studies of grip strength which make specific mention of the preschool ages. No attempt will be made to review literature dealing with grip strength for the school and adult ages at this time. However, comment will be made on pertinent results from such studies in connection with specific phases of the present investigation.

In 1900 Christopher (28) and in 1901 Smedley (108) published age means for grip strength for children of school age in the Chicago public schools. The following year Hastings (57) reported similar means for the children of Nebraska. Each of these investigators included a number of five-year-old children enrolled in the first grade, and Smedley tested a number of kindergarten children. Because of the small number of children examined, the means for five years were not considered reliable by any of the investigators reporting them. No further age means appear to have been reported until 1928, when Schwarz, Britten, and Thompson (106) presented grip strength means for New York City males from five to sixty years of age. The number of cases at five years is not given. In 1936 Meredith (87) published an analysis of grip strength data for boys accumulated by the Iowa Child Welfare Research Station. He gave means for grip strength from three to six years in six-months intervals.

The wide range of values reported at each age level is shown in the following tabulation. The means of Christopher, Smedley,

	Grip Strength, Kilograms					
	3 years		4 years		5 years	
Investigator	Number	Mean	Number	Mean	Number	Mean
			Boys			
Hastings (57)					202	4.9
Christopher (28)			16	5.0	26	6.5
Smedley (108)			41	5.5	70	7.8
Schwarz, Britten, Thompson (106)					?	7.3
Meredith (87)	41	5.1	174	7.6	317	10.2
			Girls			
Hastings (57)					183	4.7
Christopher (28)			21	5.0	37	7.0
Smedley (108)			36	5.6	81	7.2

Hastings, and Schwarz, Britten, and Thompson are for right hand only; those of Meredith are for the stronger hand.

Gates (48) correlated grip strength with measures of "mental, physiological, social, and emotional maturity" for fifty-eight junior primary children (average age 5.7) and fifty-seven fourth grade children (average age 9.6). With maturity ratings made by the teachers, "nutrition," ossified carpal area, and per cent of ossification of the carpal bones, he obtained uniformly low correlations. He reported only the averages of his correlations for the four age-sex groups.

Johnson (68) studied the grip strength of 262 children ranging in age from three to thirteen years who were pupils in the City and Country School of New York City. Twenty-one of her cases were of preschool age, and five were below five years of age. The mean values reported for these younger children are very irregular. The correlations reported were obtained from the entire age range with the two sexes combined.

Jersild (67) used grip strength in a study of learning and maturation of preschool children. Using two matched groups of twenty-three children each, four to six years old, he investigated the effects of practice on grip strength scores. After four initial trials, for which he reported split-half reliabilities of .82 and .90, he gave one group forty-three practice sessions over an eleven week period. At the end of this time he found the practice group significantly superior to the control group, but this superiority disappeared during the following three months when neither group practiced the test. He attempted a similar experiment testing the strength of the back with the Sargent back and leg dynamometer, using matched groups of sixteen children, twenty-four to forty-seven months old. His results were not reliable, and he commented: "The children in the present experiment showed somewhat less interest than the children who were given practice with the hand dynamometer." (p. 45)

Blackhurst (21) studied the value of play apparatus in developing motor control in preschool children, using as one of her criterion measures a strength test. She devised an apparatus consisting of weights attached to ropes running over pulleys. The child stood with his back to the wall to which the apparatus was fastened, grasped the handles attached to the ropes, and attempted to raise the weights. The score was the distance the weights travelled up-

ward. She found no significant change in the strength scores of her groups at the close of the experimental period.

Chase (27) investigated the effect of various types of motivation on 213 children from twenty-seven to ninety-six months of age. She devised two instruments to measure the amount of strength exerted, one which required the child to compress a rubber bulb and one which used a pair of levers. Both devices were so arranged that the experimenter could read the child's actual record but controlled the results which the child saw. She found that success accompanied by praise or reward was the most successful motivator. Since her instruments were not standardized, her means may not be used for comparative purposes.

Heinlein (58) studied the dextrality of sixty children, four to twelve years of age, giving them a series of tests, including grip strength, once a year for five years. Her data include two children four years old and eleven who were five years old at the beginning of the experiment. Dividing her cases into those who were consistently right handed, consistently left handed, and inconsistent on the repeated tests, she found that both of the four-year-old, and four of the five-year-olds were inconsistent, the remaining seven five-year-olds being consistently right handed. She stated: "No consistent tendency toward increase or decrease in difference between the two hands was noted." (p. 95)

It is evident from this discussion of previous studies which have made mention of the grip strength of preschool children that little specific information concerning the reliability and significance of the test for this age range is available. Only three studies (Jersild, Blackhurst, and Chase) are concerned specifically with preschool children, and of these one is a study of learning, one a study of motivation, and one a study of the effect of exercise on strength using an apparatus which has not been standardized. In the other studies mentioned, the information concerning the strength of preschool children has been only incidental to that for the school ages. Means for grip strength based on a fairly large number of cases are available for boys from three to six years (Meredith (87)) but these data have been obtained with the standard adult instrument which is admittedly too large for preschool children to handle effectively.

In no study has an attempt been made to investigate the problems of administration of the test specific to this age, and no study

has been reported on the relationship of these tests to other measures of physical and mental growth during the preschool period. In short, the area of grip strength for preschool children is practically an untouched field.

CHAPTER X

THE DYNAMOMETER

For measuring strength of grip three types of instruments have been commonly used: (1) the Collin type dynamometer, used by many early investigators, which consists of an oval steel frame attached to a scale which measures the distortion of the frame when it is compressed; (2) the manuometer, introduced slightly later, which consists of two heavy springs mounted between two steel bars which are curved to fit the hand. Pressure on the bars compresses the springs, and the amount of compression is indicated on a scale which covers the springs; (3) the Smedley dynamometer, devised about 1900, which has a single spring mounted on the back of a large circular scale. Attached to this is a fixed rectangular handle enclosing a second movable handle or stirrup. By means of a screw arrangement the distance between the fixed and movable stirrups can be adjusted to the size of the hand. The movable stirrup is attached to the spring in such a way that when the two stirrups are grasped the spring is compressed, and the amount of force exerted is registered on the circular scale.

Griffitts (54) compared the results obtained with the elliptical (Collin type) dynamometer and the Smedley dynamometer adjusted to the same handle size, and found that the readings on the Smedley dynamometer were from 19 to 63 per cent greater than those made on the elliptical one. He commented:

> ". . . force exerted on the Smedley is considerably greater than that exerted on the elliptical instrument. In testing grip, the muscles involved in the flexion of all the fingers are being tested. It is impossible on the elliptical dynamometer to get the full advantage of the muscles flexing the index and little fingers. This is probably the main reason for the fact that so much more force is exerted on the Smedley than on the other instrument. . . . Strength of grip evidently depends upon what is being gripped." (p. 123)

Wallin (121) experimented with a Smedley dynamometer by hanging weights from each side and from the middle of the stirrup. He stated:

> "Pulls on the right and left side of the stirrup practically always gave a different reading, usually amounting on the average to a fraction of a kilo . . . the middle pull in all cases gave the highest registration—presumably because the pulls at the ends occasion friction along the sides of the piston. . . . The difference between the middle and side pulls ranges between 1.4 and 3.2 kgs. . . . a difference so large as seriously to threaten to vitiate dynamometry work. Consequently it is of the utmost importance in testing with the Smedley dynamometer that the subjects exert the pressure along the middle of the stirrup. . . . The testing with the same weights sometimes differed quite considerably on different days. . . . This may possibly be due to temperature or other atmospheric changes which may alter the tension of the spring." (p. 64)

Kohs (73) conducted similar tests with another dynamometer and found differences of .25 to .90 kg. for successive readings with the same weight. He averaged the amounts of error per 5 kg. and worked out a correction constant. Examining Wallin's data, he found that for the dynamometer Wallin used, a different correction constant was needed. He concluded:

> "The folly, therefore, of comparing tables of uncorrected dynamometer readings is, no doubt, evident. The same holds true, of course, when individuals, low and high, of a homogeneous group are compared. . . . Unless corrected, the dynamometer readings do not accurately register the force applied. . . . Error ratios (error indices) of dynamometers vary. Therefore the error index of each, and the correction constant for each should be determined. . . . Tabulations of dynamometer reactions should be corrected before publication." (p. 310-11)

At the Iowa Child Welfare Research Station, it has been the custom to have the dynamometers checked in the physics laboratory before beginning any extended testing program. Slight adjustments are frequently necessary, but when these are made, the instruments have been found to be reasonably accurate for weights above 10 kilograms. For lighter weights, however, the error is rather large, since a disproportionately great part of the lighter weight is used in overcoming the initial inertia of the heavy spring.

Smedley (108) began his testing with the manuometer but he found that:

> "An attempt to test the young children with this instrument proved that it was entirely unsuited to the size of their hands. Those with the smallest hands were forced to use a different set of phalanges from those which the adult would

> use on the same instrument. Again it was found that the adult could make his best record only when the instrument was suited to the size of his hand." (p. 59-60)

This experience led him to design the Smedley dynamometer, which has an adjustable handle.

That the Smedley dynamometer did not entirely solve the problem of a suitable instrument for testing young children is indicated by Dewey, Child, and Ruml (36), who wrote:

> "The size of the dynanometer [sic], which is made for the adult hand, makes the test unfair to some subjects. The bars of the grip are so broad and thick that the smaller children cannot get a very firm hold and so are probably considerably handicapped in their performance. But, since it is obviously impossible to have a sufficient number of dynanometers to exactly fit the hands of all children from eight to thirteen years of age, and since the result cannot be regarded as an absolute physical measure, the inequalities of the results seemed to be minimized by giving the same instrument to all the subjects and making every effort to secure maximum effort." (p. 64)

Johnson (68) reported a similar experience:

> "The instrument is unsatisfactory for small children. The breadth and thickness of the bars prevent the smaller children from getting a firm hold and probably cause a discomfort which handicaps the performance in succeeding trials." (p. 40)

Three other factors, not mentioned by the above investigators, are as follows:

1. The weight of the Smedley dynamometer should be considered. This instrument weighs .60 kg. For large children or adults with a grip of 20 to 60 kg., this is not a great amount. They can handle the dynamometer easily, and the weight of it probably introduces little error into the reading obtained. But for a small child with a grip of 8 kg. this weight becomes rather great, making the instrument awkward to handle and adding to the difficulty of performing adequately.

2. The scale is another factor. The Smedley dynamometer is scaled in kilograms, so that the score must be read in full kilograms or estimated to the nearest half kilogram. The distance between any two kilogram marks is only 2 mm. so that the slightest slip of the indicator, any error in the adjustment of the indicator, or failing to look straight down on the face of instrument in taking

the reading, may introduce an error of as much as 1 or 1 ½ kgs. For a grip of even as much as 10 kg., this represents a considerable amount of error.

3. There is a problem of motivating the small child to exert maximum effort with the large Smedley dynamometer. If the child exerts a force of 10 kg., the only visible result is the movement of the pointer over a distance of 2 cm. There is little incentive to exert greater effort to get it to move 2 mm. farther to 11 kg. With older children the actual scores may become incentives to greater effort, but with young children, the numbers 10 and 11 may seem very much the same.

Considering all of these factors, it seemed that while the Smedley dynamometer was probably the best instrument available for measuring the grip strength of children, it was not suitable for use with preschool children if maximum and accurate records were to be obtained. Consequently, plans were drawn for an instrument which would meet the following requirements:

1. Be reasonably light in weight.
2. Be accurate over the range covered by preschool children.
3. Have a narrow handle adjustable to the largest and smallest hands likely to be found among preschool children.
4. Be easily and accurately read to at least half kilograms.
5. Be attractive in appearance.
6. Have some provision for motivating maximum effort.

To get an estimate of the size and range of adjustment necessary for the handle of the dynamometer, several X-rays of the hands of boys and girls at each age from two to eight years were taken from the Iowa Child Welfare Research Station files, and the length of the third metacarpal bone was measured. The maximum capacity likely to be needed for the instrument was determined by consulting tables giving the range of grip strength reported by Meredith (87) for Iowa City boys from three to seven years of age. The maximum grip strength recorded by Meredith for a seven-year-old boy is 21 kg. A value of 22 kg. was selected for the capacity of the dynamometer, as being a value not likely to be exceeded by preschool children.

With this information at hand, several designs were sketched, and with the co-operation of J. G. Sentinella, the dynamometer shown in Figure 4 was constructed.

The diameter of the circular scale is 16 cm. The stationary handle

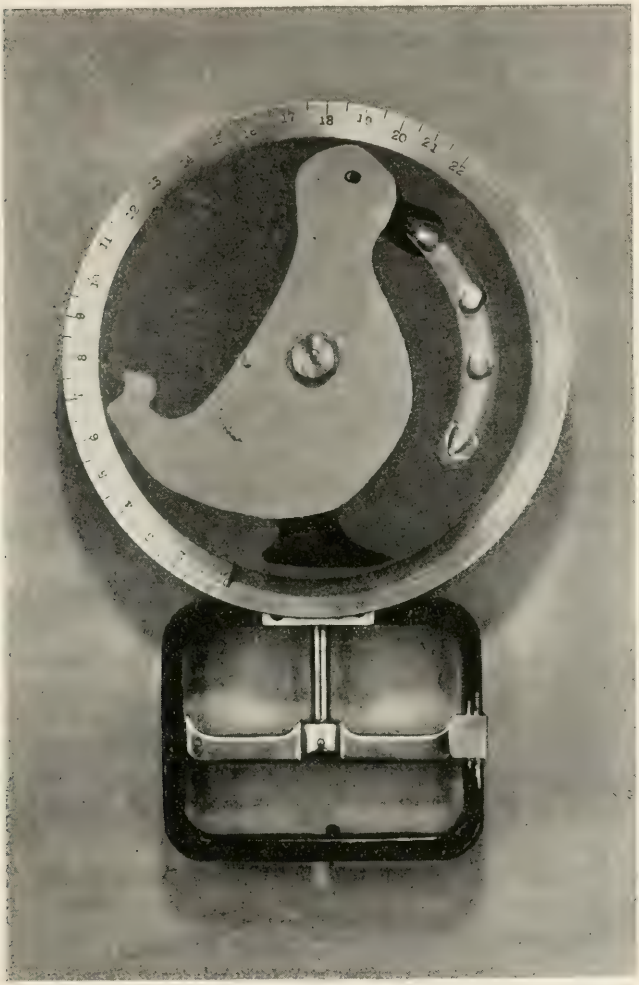

FIGURE 4. THE DYNAMOMETER "DYNA: THE HUNGRY DUCK."

measures 9.0 cm. by 6.5 cm., inside dimensions. The movable stirrup may be adjusted to give a grip as narrow as 2.5 or as large as 6.0 cm. A single bar was used instead of the rectangular stirrup of the Smedley dynamometer in order to keep the instrument as light as possible. The vertical rod running from the center of the stirrup to the spring insures a center pull being used. Two fingers are placed on either side of the rod, so that there is no danger of the child's hand slipping to either end of the stirrup. A light clamp

keeps the adjustable handle from turning in the child's hand. When this clamp is slipped back, the distance between the single bar stirrup and the stationary handle may be made less or greater by turning the stirrup either to the right or to the left.

Except for the spring, the entire instrument is made of aluminum casting. The spring is of steel and is much lighter than the larger spring of the standard instrument. The weight of the dynamometer is .34 kg.

A second movable circular plate which revolves with the indicator is mounted in front of the circular scale which carries the spring. On this plate is painted a yellow duck with an open bill. Under the opening, on the lower plate, are grains of corn. As the spring is compressed, the top plate turns, and the illusion of the duck eating the corn is created. The greater the force exerted, the farther the duck turns, and the more corn he appears to eat. For this reason, the instrument was christened, "Dyna, the Hungry Duck."

The instrument has a capacity of 22 kg. and the stationary circular plate is calibrated in half kilograms, marked at intervals of .65 cm. It is possible to estimate the score made to tenths of a kilogram. The scale was calibrated by hanging weights from the center of the handle and is accurate to .1 kg. after the 3 kg. mark is passed.

It is believed that this instrument meets the specifications of a good dynamometer for use with preschool children. It is light in weight and accurate over the range of strength for those ages. A straight pull is insured by the center rod in the stirrup. It may be read to .1 kg. It is attractive in appearance, and a motivating device helps to make it interesting to the child and aids in insuring maximum effort.

CHAPTER XI

ADMINISTRATION OF THE TEST OF GRIP STRENGTH TO PRESCHOOL CHILDREN

TESTING PROCEDURE

The procedures recommended in using the dynamometer to obtain grip strength differ as to: (1) the adjustment of the size of the handle from individual to individual; (2) the position in which the instrument shall be held; (3) the number of trials to be used in obtaining an estimate of the individual's strength; and (4) the type of instructions and motivation to be employed.

Adjustment of the Handle

Smedley (108) wrote:

> "A distance between the bars corresponding to about one-half of the distance from the place where the thumb joins the hand to the end of the fingers, was found best suited to the hands." (p. 59-60)

Dewey, Child, and Ruml (36) adjusted the handle of the dynamometer so that "the lower edge of the upper grip lies along the base of the middle fingers and the lower edge of the lower grip lies against the heel of the hand." (p. 63) Whipple (125) gave more detailed instructions:

> "With a millimeter rule, measure the distance from where S's thumb joins his hand to the end of his fingers. Adjust the dynamometer by whirling the inner 'stirrup' until the scale on the outer stirrup indicates one-half of this distance. This should bring the second phalanx to bear against the inner 'stirrup,' and will ordinarily prove to be the optimal adjustment; if not, it may be modified to suit S's inclinations." (p. 74-75)

Johnson (68) found Whipple's directions unsatisfactory, and used the "inner stirrup at the base of the middle fingers." (p. 40) Jersild (67) stated simply: "The grip of the dynamometer was adjusted to suit the advantage of each child," (p. 25) while Meredith (87) wrote similarly: "The adjustable stirrup of the instrument is regulated in accordance with the size of the subject's hand." (p. 127)

The importance of the adjustment of the handle was demonstrated by Binet and Vaschide (20). Using as subjects forty-five boys ranging in age from ten to fourteen years, they experimented with two elliptical dynamometers, one measuring 12.5 cm. by 5 cm. and one measuring 9.5 cm. by 3.8 cm. They found that for those hands measuring 13 to 14 cm. in length, the best results were obtained with the small dynamometer. For hands greater than 16.5 cm. the best results were obtained with the large dynamometer, and for hands 15 to 16 cm. there was little difference in the results obtained with the two dynamometers. They pointed out that when the large dynamometer was placed in a small hand, the subject exerted the force with the second phalanges, while with the small dynamometer the first phalanges were used. When the small dynamometer was placed in a large hand, the upper bar rested against the proximal end of the first phalanges or against the metacarpo-phalangeal joints, making it difficult to exert maximum pressure upon it.

Position

The position of the arm and hand while the test is being made has been discussed by several investigators. MacDonald (82) stated that the dynamometer "is squeezed in the hand while the arm is held out horizontally from the side of the body." (p. 1003) Wallin (121) wrote:

> "The instrument, properly adjusted to the size of the hands, was placed by the experimenter, dial up, in the subjects' hands so that the palms always faced up. Two results thereby follow: (1) the subjects were able to see the movement of the registration pointer; and (2) the thumb sides of the two hands, which probably exert a greater pressure than the little finger sides, came into contact with the opposite ends of the stirrup of the dynamometer. This circumstance may be of some importance in dynamometry work, as indicated by a series of calibration tests of the instrument, which showed that the same weight on the two sides of the stirrup does not give exactly the same reading." (p. 63)

Pyle's directions (99) stated that the subject "takes the dynamometer in the hand, holds it by his side but not touching the body. . ." (p. 47) Dewey, Child, and Ruml (36) suggested the same procedure, while Meredith (87) and McCloy (80) both mentioned that no contact of the arm with the body should be permitted, but did not further describe the position. Rogers (104) in his directions for administering the test wrote:

> "The hand should not be allowed to touch the body or any other object while taking the test. Maximum gripping power is impossible when the arm is straight. It should be flexed as in the illustration. The subject's hand should describe a sweeping arc downward as he squeezes." (p. 13)

Trials

The best of three trials for each hand has been used as the score by practically all investigators. Among the exceptions: Porter (96) apparently gave but one trial; Gates (48) gave "three trials to new children and once to those who had the 'knack' "; (p. 333) Meredith (87) gave at least two trials with each hand and used the score of the best trial of the stronger hand; Christopher (28) and Smedley (108) gave repeated trials until the subject "fell short of the best record he had made"; (p. 30) Jersild (67) used four or more trials; and Binet and Vaschide (20) used the best of five trials.

The effect of practice was studied by Jersild (67) using forty-six children, four to six years of age. Twenty-three were given forty-three practice periods over an eleven-week period and twenty-three were used as controls. At the end of the practice period the practice group exceeded the controls but the difference diminished during the next few months when neither group practiced the test.

Motivation and Instructions

Motivation and its effect on the score made has been discussed by several investigators. While almost all experimenters have noted that the child was urged and encouraged to exert maximal force, a somewhat more extreme procedure was described by Jersild (67):

> "The experimenter entered into the project with appropriate abandon; cheer-leader tactics while the child was squeezing the instrument, congratulations, handshakes, and applause when a past record was broken, a red-pencilled entry of the score when a new high was attained, and other devices gave the project much of the flavor of an athletic event." (p. 26)

Strong (115), working with adults, investigated the effect of various types of suggestion on dynamometer scores, taking twenty-eight readings on each hand. He used such remarks as: "Now you can make it stronger than usual," "Now you can't make it as strong as usual." His results were not clear cut, but were considered by him to support the conclusion that "when amount of muscular effort is called for, any arousal of the attention to the

work acts as a stimulant and enables the person to do better than he would otherwise have done." (p. 292)

Chase (27), using the strength testing apparatus previously described, studied the effect of various types of motivation on the effort put forth by 213 children, aged twenty-seven to ninety-six months. She concluded:

> "a. The means of the success-repetition, the success-praise, and the success-reward groups were all higher than the mean of the control motivation group. . .
>
> "b. The mean of the success-praise group was higher than the mean of the success-repetition group but the difference was not statistically significant. . .
>
> "c. The mean of the reward group is higher than that of the praise group but the difference is not statistically reliable.
>
> "d. The mean of the reward group is higher than that of the repetition group and the reliability of the difference approaches significance." (p. 111)

Anderson and Smith (4) repeated this experiment after a three-year interval on 102 of Chase's subjects. In general their results were similar to those reported by Chase, namely that motivation produced better scores than did no motivation.

Wallin (122) summarized the factors which might enter into the results obtained from grip strength tests:

> "The amount of exertion which an individual can make varies more or less with intelligence, the amount of available effective energy, the size, tonus, and nutritional state of the muscles, fatigue, anemia, climatic conditions, feelings of depression, exhilaration, embarrassment, timidity, or anger, and the nature of the incentives that are employed. Suggestion, rivalry, competition, and knowledge of the results of the test are among the most effective incentives. The race horse runs faster when stimulated by a 'stimulus' horse. Three subjects when hypnotized exerted forty per cent more energy than when normal. When told they were strong, they squeezed almost five times as hard as when told they were weak." (p. 497)

A similar discussion was given by Whipple (125):

> "If the test is taken under stimulating conditions, such as competition, personal encouragement, public announcement of records, etc. Binet and Vaschide found that the average grip was increased about 3 kg. or so much that the left hand surpassed the previous record of the right hand made without such incitement. Similarly, Schuyten found that ennui, or loss of

interest in successive tests, is sufficient to obscure the fatigue-effect of a school session. . .'' (p. 77-78)[9]

This review of the literature on the administration of the test raised several questions as to the best method of administering the test to preschool children. These questions seemed to require further investigation before any standardized procedure for use with this age group could be adopted or recommended. Those which seemed of primary importance were:

1. The effect of the position of the hand and arm on the grip strength score
2. The effect of time of day
3. The most appropriate manner of presenting the test to young children in order to secure the best understanding and co-operation
4. The manner of motivating the test in order to eliminate mistakes in technique and secure maximum scores
5. The number of trials and the spacing of these trials to secure a maximum, reliable score.

Each of these problems was studied, and the results of these investigations are presented below.

Adjustment of Handle

No controlled experimentation was carried out to determine the optimum adjustment of the handle size relative to the child's hand, but a little informal experimentation with a few children confirmed Binet and Vaschide's observations. If the handle span is too great or too small the position is uncomfortable for the child and smaller scores result. Adjustment of the handle so that when the lower margin of the stationary handle rested at the angle of the thumb and the upper margin of the adjustable handle rested at the base of the middle finger, proved the most acceptable to the children, and seemed to give consistently higher results. This adjustment was adopted as the standard for this study.

Preferred Hand

It was decided arbitrarily to use the score made by the stronger hand rather than that of the right or left exclusively. Evidence will be presented in Chapter XIII to show that a significant number of children at each age make their best scores with their left hands. To use the sum of the scores for both hands introduces an-

[9] The writer has been unable to locate the source of these findings of Binet and Vaschide and of Schuyten.

other factor into the data. Some children are noticeably more awkward with one hand than with the other, and it was observed that consistently lower scores were produced with the more awkward hand. Considering this, it seemed that to add the scores in such cases might give a composite which would be difficult to interpret.

Position of the Hand and Arm

Consideration was given to three positions of the hand and arm. In each position two fingers were placed on each side of the vertical rod which rises from the center of the adjustable stirrup.

1. The arm was held down at the side. The arm hung at the side in a relaxed position with the palm of the hand facing inward. The dynamometer was placed in the child's hand and he gripped it, keeping the arm far enough away from the body so that no contact was made between them.

2. The forearm was flexed at the elbow and the hand was in pronation. The elbow was flexed to approximately a right angle and the hand extended with the palm facing downward. The experimenter placed the handle of the dynamometer in the child's hand and allowed the circular plate to rest lightly on her own outstretched hand. The experimenter's hand bore the weight of the dynamometer, but offered no resistance to the child's grip. If the child tended to bear down on the dynamometer or to pull it toward him, the experimenter allowed her supporting hand to "give" with the pressure or permitted the dynamometer to slide off her hand with the pull. The elbow was not in contact with the side while the grip was being made. The experimenter on occasion placed her free hand lightly on the inside of the child's arm if he tended to push it against his side.

3. The forearm was flexed at the elbow and the hand was in supination. This position was the same as (2) except that the palm of the hand faced upward.

To study the differences in results for the three positions, thirteen Junior Primary children were used. The experiment was so planned that differences due to position, differences due to time of day, and differences between the results obtained by two testers might be investigated simultaneously. Three trials with each hand were given to each child on Wednesday, Thursday, and Friday of one week and on Monday, Tuesday, and Wednesday of the following week. On each day each child was tested at 9:00 and again at 11:00 o'clock. Positions and observers were rotated so that each child was tested at each time of day in each position by each observer, making twelve

tests for each child. These data were arranged in a factorial design consisting of 13 children by 3 positions by 2 times of day by 2 observers. The means of the scores for position, time of day, and observer groupings are shown below. The scores for the individual children are not given.

	Observer A		Observer B		Mean	
Position	Number	Mean	Number	Mean	Number	Mean
Supination	13	12.75	13	12.18	26	12.47
Pronation	13	12.09	13	11.99	26	12.04
Down	13	12.15	13	12.15	26	12.15
Total	39	12.33	39	12.11	78	12.22

	9:00 o'clock		11:00 o'clock		Mean	
	Number	Mean	Number	Mean	Number	Mean
Supination	13	12.33	13	12.60	26	12.47
Pronation	13	12.08	13	12.00	26	12.04
Down	13	12.25	13	12.06	26	12.15
Total	39	12.22	39	12.22	78	12.22

From these data the following estimates of the variance of the population were computed:

	d.f.	Variance
Positions	2	2.5362
Observers	1	1.9408
Times	1	.0000
Children	12	50.7348
Positions by children	24	1.7154
Error*	115	.6170

* The other possible interaction variances were also computed, but since there were no significant differences among them, they were combined to give one more stable error term.

Comparisons of the observers and times variances with the error variance give insignificant F's, indicating that the differences due to observer or time of day were no greater than could be attributed to chance.

The interaction variance (positions by children) is significant at the 1 per cent level ($F = 2.78$) indicating that the same position is not equally effective for all children. Using this interaction variance to evaluate the variance for positions gave an F of 1.48, which is not significant for 2 by 24 degrees of freedom, but when the positions variance is compared with the error variance, an F of 4.11 is obtained, which is significant at the 5 per cent level for 2 by 115 degrees of freedom. In this instance it is possible to say only that the variance for positions means is significantly greater than the child variance. This does not indicate that one position was consistently best for all children.

Using the standard error of the difference computed from the

error variance, a difference of .40 in the means for the position groups will give a "t" which is significant at the 1 per cent level, and a difference of .29 will give a "t" which is significant at the 5 per cent level. The observed differences in the means are:

Position	Difference	
Supination-pronation	.43	Significant at the 1 per cent level
Supination, down	.32	Significant at the 5 per cent level
Down-pronation	.11	Not significant

The results of this analysis are not entirely conclusive. They indicate that for this group of children and others like them the supinatory position gives results which are significantly higher than those obtained with the hand in pronation, but generalization to all children is prohibited by the fact that the variance for positions is not significantly greater than the interaction variance.

From an administrative point of view it seemed desirable to use only one hand position with all children. If there were no significant differences in the results obtained with the various positions, then the choice of position was a matter of no great moment, and that position could be selected which was the easiest to administer. However, if one position gave consistently higher results it should probably be chosen regardless of the ease of administration.

The analyses made showed no highly significant differences between the results in the three positions used, but the evidence tends to indicate that, if any position is the best for most of these children, it is the position of supination. It was therefore selected as the position of choice for this study.

Two further considerations influenced this choice. (1) In the "down" position the face of the dynamometer is not visible to the child and any increased interest value which may accrue from the motivating device on the face of the dial is lost. For this reason the down position proved less interesting to the children. (2) The supination position is the easiest to administer since the child's hand is extended palm upward and the experimenter may see at a glance whether the handle is too large or too small for the hand and may readily observe the position of the fingers and anything unusual in the position of the hand as the test is being made.

Figure 5 shows a child performing the test in the recommended position. Points to be noted are the position of the child's hand

FIGURE 5. ADMINISTERING THE TEST OF GRIP STRENGTH.

and arm, and the relation of the experimenter to the child. Figure 6 shows a closer view of the child's hand as the grip is being made.

Initial Presentation of the Test

As previously described for breathing capacity, three methods were used: (1) the large group method; (2) the small group method; (3) the individualized method. Similar experiences produced similar conclusions regarding the feasibility of the three methods. No time was saved by either of the group methods, and the confusion produced by them seemed undesirable. Consequently, the individualized method was adopted for the remainder of the testing.

The experimenter visited each group several times before attempt-

ing to introduce the test. When the children were familiar with the experimenter they were taken one at a time, or two at a time if a companion was preferred, to the testing room. They were shown the dynamometer and the test was explained somewhat as follows:

> "This is Dyna, a hungry duck. She is hungry and wants to eat this corn, but she can't reach it because here is her mouth (pointing) and here is the corn (pointing). We can help her by putting our hand through the handle (demonstrating) and squeezing. If we squeeze a little bit, like this, she gets one grain of corn. If we squeeze a little harder, like this, she gets another grain. The harder we squeeze, the more corn she gets. The game is to see how much corn you can make her eat."

The instrument was then turned around and the child's hand placed

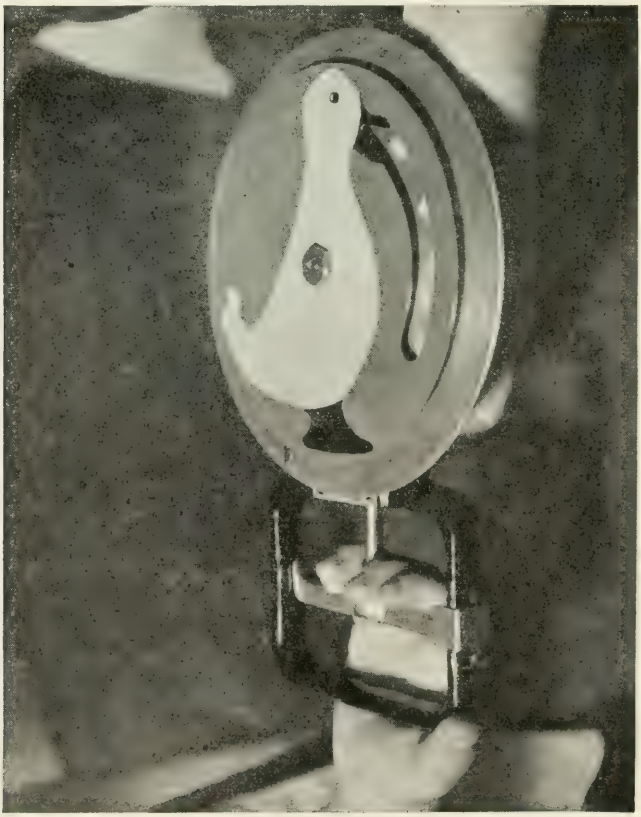

FIGURE 6. HAND POSITION USED IN TESTING GRIP STRENGTH.

on the handle, the experimenter saying: "Let's see how much corn you can help her eat." Usually the children extended their hands palm upward to receive the instrument, but if they did not the experimenter said: "Let's turn your hand over this way. You can squeeze harder."

Motivation of the Test

As in the case of breathing capacity, the interest of the child and the evident interest of the experimenter in the outcome of each trial were considered the best motivators to produce continued maximum effort. Among the informal devices used to maintain interest were: (1) always saying the score in a pleased tone of voice; (2) allowing the children to look under the movable circular plate to see how much corn there was; (3) acceding to the children's requests to "make it go all the way"; (4) counting the grains of corn out loud for the older children; (5) allowing the children who were able, to read off their own scores.

That the children were interested in the test was shown by their comments and questions. The most frequent questions were: "Why doesn't he keep the corn when he gets it?" "Why is he hungry?" "Doesn't he ever get full?" and many children never failed to ask after each trial: "How many did he get?" One three-year-old always shouted "Bite!" at the duck as he squeezed.

The children talked about the test at home and the parents were quite interested in the duck, some of them asking to see both it and the "balloon machine" when they called for their children. Some children tried to tell their parents how strong they were and how much stronger they were getting every day.

Experience with the test showed that several errors in technique occurred fairly frequently among the children. These are listed below with suggestions for overcoming them.

1. The size of the handle may be too large or too small. This can be readily corrected by adjusting the handle. This process of adjustment produced added interest on the part of the children. Many would say: "Make it so it fits me," when they came into the testing room before they took the dynamometer in their hands.

2. The finger position may be incorrect. Children sometimes get three fingers on one side of the vertical rod, producing a slightly diagonal pull which decreased the score. This may be easily corrected by saying: "Let me fix your fingers. That finger is trying to do too much work all by itself."

3. Incorrect wrist position: In this position the wrist was hyper-extended, stretching the flexors too far for efficient functioning. This produced a tendency to push against the stationary handle with the heel of the hand rather than pulling against the movable handle with the fingers. This habit was difficult to overcome in some children. The best correction seemed to be to say: "Let me fix this in your hand again," taking the dynamometer with one hand and pushing the child's hand up to the normally extended position with the other hand before giving him the dynamometer. Placing the instrument a little too far forward on the child's hand seemed to be useful in that he had to reach for it and pull it back to the comfortable position with the flexors.

4. The child may bear down against the experimenter's hand so that a push rather than a pull results. The experimenter allowed her hand to "give" with the push, and then readjusted the dynamometer in the child's hand as described in (3). This position was often accompanied by too much tension in the forearm and arm. If such was the case it seemed better to discontinue testing for a time and interest the child in something else until the tension was relaxed.

5. The child may press his elbow against his side. The experimenter would place her free hand lightly on the inside of the child's arm to remind him to keep his arm away from his body. This was particularly helpful with the youngest children.

6. The child may jerk on the handle. A quick jerk on the handle produces a slightly higher score than a steady squeeze. A few children tried to make the duck eat more by jerking. This not only defeated the purpose of the test but occasionally caused the pointer to slip from its proper adjustment. These scores were not recorded, but the child was invited to try again, the experimenter saying: "Let's do it again and see how long we can make the duck stay around there to give him time to eat the corn."

7. The child may make a series of short incomplete squeezes. It must be emphasized to the children that only one squeeze at a time may be used. Otherwise the smaller children will tend to close and open the hand several times to make the duck move back and forth, exerting incomplete effort with each small squeeze. The experimenter said: "Now hard, like this!" at the same time making her own hand into a fist and squeezing very hard.

8. The free hand may be brought over to aid in the squeeze. This was best counteracted by having the experimenter hold the child's free hand in her own, allowing the child to squeeze her hand. If the children expressed a desire to see how far they could make the duck go with both hands, they were allowed to try after the tests for the day were completed. They soon

learned that, because of the smallness of the handle, two hands are not much better than one, and they seldom asked after the first or second test periods.

Number of Trials Each Day

To determine how many trials should be given on each day fifty-six children were tested on each of three days, three trials with each hand being given each day. The scores for both hands were recorded and those for the stronger hand selected for analysis. Since it was necessary to test both hands, only three trials were given. This made a total of six trials in all, and it was difficult to maintain the children's interest very far beyond this point.

The number of times the best score was made on the first trial, the second trial, or the third trial was tabulated for each age group as follows:

Best Score Made on Trial	Years 3 (N=7)	4 (N=14)	5 (N=20)	6 (N=15)	Total (N=56)
First	29	63	81	58	231
Second	17	39	56	38	150
Third	17	24	43	39	135
Total	63	126	180	135	504

This distribution of successes is significantly different from that which might be expected by chance alone ($X^2 = 32.04$), the best score being made on the first trial 46 per cent of the time. This might be interpreted as indicating some tendency for the accumulation of fatigue with successive trials. But more than half of the highest scores occurred on the second and third trials, indicating that in many instances the children put forth greater effort on the later trials.

If there is a tendency for slight fatigue to occur after the first trial, it becomes increasingly important for the experimenter to be sure that conditions are as nearly perfect as possible for the first attempt in order to get the maximum results while the muscles are unfatigued. If the first trial is not maximum, it may be that succeeding trials will give higher scores than the first, but not as high as the first trial might have been if the technique had been better or if maximum effort had been made at that time.

In view of the fact that more than half of the best scores did occur on the second and third trials it seemed best not to attempt to reduce the number of trials to less than three with each hand.

Number of Days of Testing Necessary to Obtain a Dependable Score

Ninety-eight children were given three trials with each hand on each of six days. The best score of the three trials for each hand on each day was tabulated for each child and those for the hand making the higher scores selected for analysis. For the stronger hand the following scores were determined for each child:

The Best Score	Mean (kg.)
In 6 days of testing	10.52
In the first 5 days	10.37
In the first 4 days	10.17
In the first 3 days	9.79
In the first 2 days	9.43
On the first day	8.92

It is evident from this tabulation that the scores increase after the first day for many of the children, since the mean of the best score for six days is 10.52 kg. as compared with 8.92 kg. for the first day's scores. For the first four days of testing the average increase per day is .42 kg.; for the fifth and sixth days .20 and .25 kg. respectively. While it is possible that further increase would occur if the tests were given for seven or eight days, it seems likely that most children have made their best attempt by the sixth day and that further increases would be very slight.

The individual records were studied for each of these children. It was noted that in a few instances the best score was markedly greater than any of the other scores. This suggested the possibility that such scores represented an error. It was possible that the child had jerked on the handle instead of squeezing, or that the child had pressed his arm against his side as he squeezed, or that a mistake had been made in recording the score.

If a sufficient number of trials were given, and if the "best" score represented a true estimate, the best score should not differ greatly from the second best score. To test this hypothesis the second best scores were determined as follows:

Second Best Score	Mean (kg.)
Of 6 days' scores	10.14
Of 5 days' scores	9.93
Of 4 days' scores	9.56
Of 3 days' scores	9.06

Again the increments decrease with successive days, being .50 kg.

between the third and fourth days and .21 kg. between the fifth and the sixth days. It is evident that while increases are still occurring to the sixth day, they are becoming slight.

The best of six days' scores was compared with the second best of six days' scores for each child. The range of differences was from 0 to 1.7 kg. For 60 per cent of the cases the difference was .30 kg. or less, and for 83 per cent of the cases it was .50 kg. or less. It appears likely that some of the differences greater than .50 kg. are due to errors in the higher score.

When the second best of six days' scores was compared with the average of the three best scores for each child, the mean difference was —.004 kg., which is obviously not significant.

After studying these relationships in the light of the individual records it was decided that the second best score made by the stronger hand in six days of testing would constitute a dependable estimate of the grip strength of children at these ages. It is recognized that the choice is an arbitrary one and that other investigators might prefer to determine the score in a different manner. However, as the records used in the present study were accumulated, it seemed to this investigator that the second best score was a more dependable estimate of the strength of the children than the best score made in many instances.

In this study, then, the grip strength score was derived as follows: Each child was given three trials with each hand on six separate days. The best score made on each day with each hand was recorded. From the scores for six days for the stronger hand, the second best score was selected for use as an estimate of the grip strength of the individual.

RELIABILITY OF THE TEST

It is surprising to find that few investigators have attempted to determine the reliability of the grip strength test. The reliability coefficients available range from .45 to .94. Schwarz, Britten, and Thompson (106) reported a correlation of .83 for the grip strength of 34 high school boys who were tested in February and again in May. Their subjects were from thirteen to seventeen years of age. Rogers (103) tested 140 boys, ranging in age from twelve to nineteen years, in May and again in September. He obtained correlations of .92 and .90 for the right and left hand respectively. Johnson (68) obtained two sets of grip strength scores on fifty-seven subjects, three to thirteen years of age. She reported a correlation

of .83 for these data, but when chronological age was held constant, this correlation fell to .68.

Correlations between two sets of grip strength scores obtained from subjects of more limited age ranges have been reported for girls by Anderson (6), and for boys by MacCurdy (81), and by Jersild (67). Anderson tested 300 girls in grades ten and eleven. For the right grip the correlation between the scores was .54, and for the left .45. MacCurdy tested 103 sixteen-year-old boys on two occasions, and found a correlation of .94 between the two sets of scores. Jersild gave four trials on each of four days to two groups of nineteen children each, ages four to six years. Between the best score on the first two days and the best score on the last two days he found correlations of .82 and .90 respectively for the two groups.

In the present study test scores were available for both right and left hands for six days of testing. The reliabilities of each hand for each age-sex group were studied by comparing the highest score made on the first, third, or fifth day with the highest score made on the second, fourth, or sixth day. The range of differences for both hands was from 0 to 1.90 kg. For 52 per cent of the cases the difference was .40 kg. or less; for 90 per cent it was 1.00 kg. or less. The product-moment correlations obtained are shown:

Age	Number	Right	Left
	Boys		
2 years, 6 months to 3 years, 5 months	21	.899	.921
3 years, 6 months to 4 years, 5 months	27	.934	.916
4 years, 6 months to 5 years, 5 months	42	.912	.934
5 years, 6 months to 6 years, 5 months	26	.913	.914
All ages	116	.957	
	Girls		
2 years, 6 months to 3 years, 5 months	19	.889	.890
3 years, 6 months to 4 years, 5 months	20	.841	.909
4 years, 6 months to 5 years, 5 months	28	.894	.903
5 years, 6 months to 6 years, 5 months	19	.920	.780
All ages	86	.953	

There is some tendency for the correlations for the boys to be slightly larger than those for the girls, though the differences are not marked. All the correlations except those for six-year-old girls

(left hand) and four-year-old girls (right hand) are approximately .90.

These values compare favorably with the values of .90 and .82 reported by Jersild (67) for children four to six years of age; with the .94 reported by MacCurdy (81) for 103 sixteen-year-old boys; and with the .92 and .90 given by Rogers or the .83 given by Schwarz, Britten, and Thompson (106) for boys over the whole high school age range. They are significantly higher than the .68 reported by Johnson (68) for children from three to thirteen, with age held constant. They also exceed the values of .54 and .45 found by Anderson (6) for 300 high school girls.

The correlations obtained when all scores for the right hand over the four year age range are put into one distribution are higher than any previously reported in the literature for grip strength over any age range.

These correlations seem high enough to warrant the conclusions: (1) that reliable results may be obtained from tests of grip strength given over six days to children from two and one-half to six and one-half years of age; and (2) that such results are no less reliable than those obtained when the test is administered to older children.

CHAPTER XII

GRIP STRENGTH AS RELATED TO CHRONOLOGICAL AGE

AGE MEANS FOR GRIP STRENGTH

Grip strength averages for children of elementary and high school age have been reported by numerous investigators. Seven studies have included averages for preschool children. In all but one of these, however, the data on preschool children have been incidental to the main purpose of the study. Table 9 gives a description of the data on which the principal studies are based. The studies are arranged chronologically with reference to date of publication.

In Tables 10 and 11 the average grip strength for each age covered by these investigations is given. An attempt has been made to arrange the averages in order of magnitude. Since the order is not always the same at every year of age, the values reported at ten years for boys have been selected as the point of reference. Direct comparison of the values given is difficult. This follows since some values represent the average of three trials, some the result of one trial, some the best of three trials, some the right hand only, some the best hand, and some the average of the right and left hands. Moreover, in some studies age was taken to the last birthday and in others to the nearest birthday, making a difference of six months in the mid-point of the yearly intervals. Where specific information is reported as to the instrument used, the number of trials given, the way in which the score for each child was determined, and the specific limits of the age intervals used, this is indicated. A question mark in any column indicates that the author failed to discuss this aspect of his investigation. For the preschool ages the number of cases on which each mean is based is shown in parentheses.

Taking the values given for ten-year-old boys as representative, the means may be grouped as: Low—Schwarz, Britten, and Thompson (106), Porter (96), Arthur (11), Hastings (57), Carman (25), Christopher (28), and Smedley (108); intermediate—Reed (100), Dewey, Child, and Ruml (36), and Mead (86); and high—Baldwin ((14), 1921 and (15), 1925), Meredith (86), and Metheny (unpublished means obtained for a population of girls comparable to Mere-

Table 9
Description of Data of Principal Studies Including Age Means for Grip Strength of Children of School Age

Investigator	Date	Number			Age, Years	Description of Subjects
		Boys	Girls	Boys and Girls		
Porter (96)	1892	16,295	18,059		6 to 17	St. Louis public school
Carman (25)	1899	756	751		10 to 18	Saginaw, Michigan public school
Christopher (28)	1900	605	603		4 to 18	Chicago public school
Smedley (108)	1901	2,788	3,471		4 to 18	Chicago public school
Hastings (57)	1902	6,711	6,442		5 to 18	Nebraska public school
Mead (86)	1916	231	249		6 to 18	Caldwell, New Jersey Public school
Dewey, Child, and Ruml (36)	1920	50 at each age	50 at each age		9 to 13	New York City public school (Jewish)
Baldwin (14)	1921	60 at each age	60 at each age		7 to 17	New York City private school
Arthur (11)	1924	?			6 to 81	English (Galton's original data)
Baldwin (15)	1925	300	270		7 to 17	California "geniuses"
Johnson (68)	1925			262	4 to 13	New York private school
Reed (100)	1926	259			11 to 17	Morgantown, West Virginia public school
Schwarz, Britten, Thompson (106)	1928	2,162			3 to 60	New York public schools
Heinlein (58)	1929			60	4 to 12	New York public schools
Meredith (87)	1935	4,999			3 to 18	Iowa City private school
Metheny (unpublished)	1940		4,787		3 to 18	Iowa City private school

Table 10
Age Means for Grip Strength of Boys of School Age

Investigator	Age, Years																		Instrument	Trials	Typical Age Interval
	N	3	N	4	N	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
Schwarz, Britten, and Thompson(106)					?	7.3	7.7	9.2	10.2	11.8	12.7	14.3	16.1	18.6	22.4	27.2	33.0	39.4	39.2	Collin	Best of 3	9 years, 0 months to 9 years, 11 months
Porter (96)							6.1	7.7	9.4	11.4	12.8	14.4	16.7	19.1	22.3	26.7	31.0			?	One (?)	?
Arthur (11)							7.4	8.8	10.4	11.9	13.5	15.1	17.0	19.2	22.1	26.4	30.8	33.8	35.2	?	?	9 years, 0 months to 9 years, 11 months
Hastings (57)					(202)	4.9	7.0	9.2	10.6	13.1	14.1	18.0	19.7	22.6	25.4	28.9	33.3	43.2	46.2	Manu-ometer	2 or 3	?
Johnson (68)[1]			(2)	5.8	(13)	6.3	8.1	9.5	11.4	13.7	14.5	15.8	15.8	19.5						Smedley	Average of 3	9 years, 0 months to 9 years, 5 months 9 years, 6 months to 9 years, 11 months
Heinlein (58)[2]			(2)	5.8	(13)	7.8	9.1	10.7	12.0	12.8	14.9	16.2	18.9	22.9						Smedley	Average of 3	9 years, 0 months to 9 years, 11 months
Carman (25)											16.0	19.0	21.0	22.0	26.0	30.0	35.0	40.0	42.0	Collin	?	?
Christopher (28)			(16)	5.0	(26)	6.5	9.0	10.0	12.0	13.0	16.0	18.0	22.0	27.0	30.0	36.0	45.0			Collin	Repeated	9 years, 0 months to 9 years, 11 months
Smedley (108)[3]			(41)	5.5	(70)	7.8	9.2	10.7	12.4	14.3	16.5	18.9	21.2	24.4	28.4	33.4	39.4	44.7	49.3	Smedley	Repeated 3 trials	9 years, 0 months to 9 years, 11 months
Dewey, Child, and Ruml(36)										15.5	16.7	21.2	23.2	25.9						Smedley	Average R and L	9 years, 0 months to 9 years, 11 months
Mead (86)							8.6	10.4	13.1	15.7	18.1	21.1	24.5	26.5	31.3	40.2	50.4	53.1	52.7	Manu-ometer	?	?
Reed (100)												19.7	22.2	24.8	28.2	30.2	32.6	35.8		Manu-ometer	Average R and L	?
Baldwin (15, 1925)								13.7	13.7	18.2	19.5	22.0	24.2	26.7	31.8	37.9				Smedley	?	?
Baldwin (14, 1921)								12.6	14.8	17.7	19.8	21.8	23.8	27.7	30.3	35.0	41.7	45.3		Smedley	?	8 years, 9 months to 9 years, 3 months
Meredith (87)[4]	(41)	5.1	(105)	7.6	(173)	10.2	11.4	13.0	15.8	17.9	20.3	22.5	25.0	29.2	33.9	38.9	44.8	48.3	52.4	Smedley	2 trials best hand	8 years, 6 months to 9 years, 5 months

1 Boys and girls combined.
2 Boys and girls combined, reported in half year intervals.
3 "Birthday Norms" adjusted to make mid-point of age interval exactly 7 years, 6 months, 8 years, 6 months, etc.
4 Mean at three years obtained over age range 3 years to 3 years, 5 months. Means at four and five years reported in half year intervals. Succeeding means represent age in even years.

Table 11
Age Means for Grip Strength of Girls of School Age (in Kg.)

Investigator	Age, Years																		Instrument	Trials	Typical Age Interval
	N	3	N	4	N	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
Porter (96)							5.1	6.5	8.1	9.2	10.4	11.8	13.5	16.1	18.0	20.0	21.8	21.9		?	One (?)	?
Hastings (57)					(183)	4.7	5.2	7.5	9.3	10.1	13.0	14.1	16.0	18.5	21.7	24.4	24.1	24.1	25.3	Manu-ometer	2 or 3	?
Carman (25)											11.0	13.0	15.0	18.0	20.0	21.0	21.0	23.0	24.0	Collin	?	?
Christopher (28)			(21)	4.0	(37)	7.0	7.5	9.0	10.0	12.0	12.5	16.0	19.0	22.0	24.0	27.0	32.8			Collin	Repeated	9 years, 0 months to 9 years, 11 months
Smedley (108)[1]			(36)	5.6	(81)	7.2	8.4	9.9	11.2	12.8	14.7	16.5	18.9	21.8	24.8	27.0	28.7	29.6	29.8	Smedley	Repeated 3 trials	9 years, 0 months to 9 years, 11 months
Dewey, Child, and Ruml (36)										14.0	15.1	17.5	19.8	24.0						Smedley	Average R and L	9 years, 0 months to 9 years, 11 months
Mead (86)							7.6	8.0	9.7	12.1	14.1	17.3	22.9	24.3	29.6	32.0	33.5	32.1	33.3	Manu-ometer	?	?
Baldwin (15, 1925)								10.4	12.6	15.4	16.1	19.8	21.2	26.0	28.0	31.9				Smedley	?	?
Baldwin (14, 1921)								11.2	13.2	15.9	18.5	20.0	22.0	25.2	28.1	30.4	32.3	32.2		Smedley	?	8 years, 9 months to 9 years, 3 months
Metheny[2]	(30)	4.3	(55)	6.4	(90)	8.4	9.2	10.7	12.5	14.6	16.5	19.1	21.7	26.0	28.5	30.6	31.4	32.2	33.1	Smedley	2 trials best hand	8 years, 6 months to 9 years, 5 months

1 "Birthday Norms" adjusted to make the mid-point of each age interval exactly 7 years, 6 months, 8 years, 6 months, etc.
2 Mean at three years obtained over age range 3 years to 3 years, 5 months. Succeeding means represent age in even years.

dith's boys). Heinlein (58) and Johnson (68) are omitted from comparison since the two sexes are combined in their studies.

With the exception of the Schwarz, Britten, and Thompson study, all of the low values were obtained prior to 1902. Arthur did not publish until 1924, but his data were obtained by Galton in the nineteenth century. All of the low values were obtained on public school children, and those given by Carman, Christopher, and Schwarz, Britten, and Thompson were obtained using the Collin type dynamometer.

The intermediate values given by Reed, Mead, and Dewey, Child, and Ruml were obtained during the years 1916 to 1926 on public school children with either the Smedley dynamometer or the manuometer. Jewish subjects were used by Dewey, Child, and Ruml.

The high values given by Baldwin, Meredith, and Metheny were all obtained during the last two decades on private school children, with the Smedley dynamometer.

In general, it would seem that the highest means have been obtained during the last two decades, on private school children, using the Smedley dynamometer. It is not possible by means of the available studies to determine the relative importance of socio-economic factors and several other factors (e.g., climatological, etc.) possibly involved.

For comparative purposes in the present study, the means given by Baldwin (14), Meredith, and Metheny were used. Those given by Meredith and Metheny are particularly useful since they are based on the same population as that from which the subjects of the present study were drawn.

Table 12 gives the grip strength findings of the present study at each age from three to six years. It will be recalled that these findings are based on the score made by the stronger hand in six days of testing.[10]

From this table the following observations may be drawn:

1. There is an increase in grip strength from year to year for both sexes.
2. For boys, the mean grip strength at six years is 5.18 kg. (65.4 per cent) greater than at three years. For girls the comparable gain is 4.42 kg. (64.7 per cent).
3. For boys the mean grip at three years is 60.4 per cent of that at six years, for girls 60.7 per cent.

[10] The number of children for whom the left hand was the stronger, the right hand was the stronger, or the hands were equally strong is given in Chapter XIII.

Table 12

Central Tendency and Variability Values of Grip Strength, Kg., at Each Year of Age from Three to Six (Stronger Hand)

Age	Mean Age, Months	Number	Mean Grip Strength	Range	Standard Deviation	Coefficient of Variation	Per Cent of Mean at 6 Years	Mean of Scores First Day
Boys								
2 years, 6 months to 3 years, 5 months	37	21	7.92	5.1 to 9.7	1.35	17.1	60.4	7.66
3 years, 6 months to 4 years, 5 months	49	27	9.52	6.0 to 13.8	1.67	17.3	72.7	8.31
4 years, 6 months to 5 years, 5 months	60	42	11.72	7.0 to 16.5	1.93	16.5	89.5	11.00
5 years, 6 months to 6 years, 5 months	70	26	13.10	9.3 to 17.0	1.93	14.7		12.32
Girls								
2 years, 6 months to 3 years, 5 months	37	19	6.83	4.3 to 10.0	1.19	17.5	60.7	6.25
3 years, 6 months to 4 years, 5 months	47	20	8.91	6.5 to 11.1	1.28	14.3	79.2	8.29
4 years, 6 months to 5 years, 5 months	58	26	10.09	7.0 to 12.6	1.48	14.7	89.7	9.34
5 years, 6 months to 6 years, 5 months	70	19	11.25	9.5 to 13.6	1.00	8.9		10.73

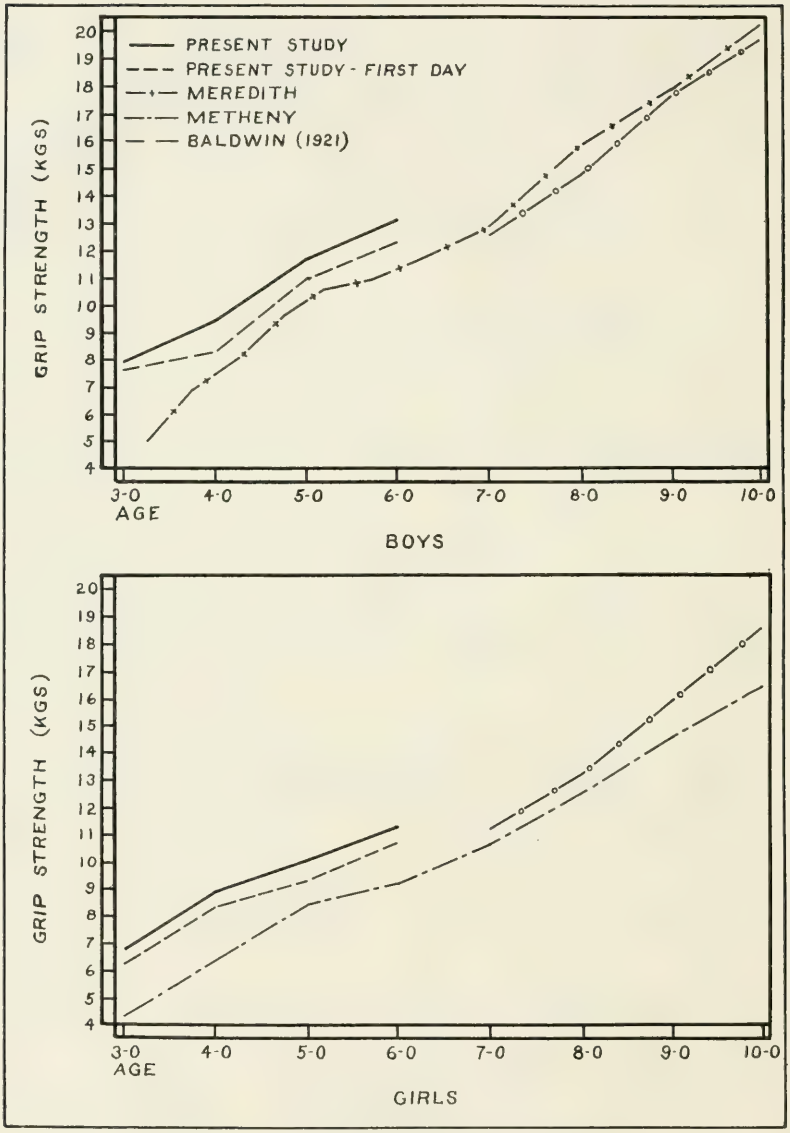

FIGURE 7. AGE MEANS FOR GRIP STRENGTH.

4. The average annual increase in grip strength is 1.73 kg. for boys and 1.47 kg. for girls.

5. At each year of age the greatest grip strength recorded is approximately twice the smallest.

6. There appears to be a slight tendency for the variability to decrease with age, as shown by the coefficients of variation. They range from 17.5 to 8.9, the average being 15.1.

7. The boys exceed the girls in mean grip strength at each age level. (This finding will be discussed in more detail later).

8. For each age group the obtained mean grip strength from six days of testing is from .3 to 1.2 kg. greater than the mean of the scores made on the first day of testing.

It is of interest to compare these findings, both as to growth and variability, with those from comparable data at the older ages.

Meredith reported that boys increased in grip strength 359 per cent from six to eighteen years of age. For the Iowa girls the comparable figure is 260 per cent. In the present study, both boys and girls increase about 65 per cent in grip strength from three to six years of age.

As to variability, Meredith found the average coefficient of variation for boys from three to eighteen years of age to be 21.7. The coefficient decreased from 34.5 at three years to 17.6 at ten years, rose slightly from ten to twelve years, and decreased to 16.6 at eighteen years. Baldwin (14) noted a similar trend for boys from seven to seventeen years of age, and found that the coefficient for girls decreased from 30.3 at seven years to 12.4 at seventeen years with no increase at adolescence. The average coefficient of variation (15.1) found in the present study from three to six years is lower than that found by either Baldwin or Meredith. This is probably a result of the better testing conditions employed, which tended to eliminate much chance variation.

A graphic comparison of the means shown in Table 12 with those given by Baldwin, Meredith, and Metheny is made in Figure 7.

It will be noted that the present means are higher than those given by any other investigator, but that the curves are essentially parallel except from three to four years for the boys. Possible reasons for the higher values found in the present study may be:

1. The smaller, lighter instrument is easier for the children to use, and the smaller initial inertia of the spring makes the instrument more accurate for the smaller grips. The difference due to the use of the small instrument was investigated by testing thirty-four junior primary children with the standard Smedley dynamometer after they had learned the technique of gripping with the small one. The mean grip strength registered on the large dynamometer was 10.2 kg. as compared with a mean of 11.5 for tests made the preceding day with the small

dynamometer. The difference was significant (by the "t" test) at the 1 per cent level.

2. More time for learning the technique of taking the test was given in the present study, the scores being the second best of six days' trials rather than the best of three trials on one day. That this is an important factor is shown by the fact that the mean scores for the first day's tests more closely approximate the mean scores given by Meredith and by Metheny.

3. More time was spent in the present study in obtaining and fostering the children's interest in the test, also better motivation was obtained by the use of the pictorial dial. It is believed that the conditions necessary for obtaining maximum effort on the part of each child were more advantageous in the present study than in those with which comparison is being made.

After allowance is made for the consistently higher values found in the present study, the curves may be considered as being consistent in form with those given by Meredith and Metheny for these ages, and as a continuation downward of the curves given by Baldwin for the older ages.

Meredith (87) described the "mean course of growth" for grip strength of boys as follows:

> "There is a relatively slow and constant growth below twelve years, a period of rapid increase between twelve and sixteen years, and a phase above sixteen years indicating a decline in growth rate." (p. 39)

The curves obtained in the present study, both for boys and for girls, are consistent with the description of a period of "constant growth" below twelve years.

SEX DIFFERENCES

For grip strength, as for breathing capacity, the majority of investigators have reported their findings separately for the two sexes, thus implying the existence of a sex difference in grip strength. Carman (25) noted in 1899 that "Girls are . . . weaker at all ages than boys." Her study included children from ten to nineteen years of age. Smedley (108) confirmed this finding in his study of Chicago school children. He wrote:

> ". . . the boys surpass the girls in strength at all ages; even in the kindergarten the average boy is stronger in his left hand than the average girl is in her right hand, and during the early years of adolescence this differentiation of the sexes becomes

> very striking. . . . The curve representing the strength of the boy's left hand runs nearly parallel to the curve representing his growth in weight, and in the earlier years of adolescence the curve representing the strength of the right hand gradually approaches the curve of weight. With the girls the lines representing strength and weight gradually become farther and farther apart." (p. 60)

Baldwin stated (14):

> "Girls are inferior to boys in all strength tests, girls showing, after 15 years of age, little increase, and frequently a decrease in strength." (p. 94)

Johnson (68) stated that boys were superior to girls in grip strength at all ages from 3.5 to 13 years.

In the present study it was noted that the mean grip strength for boys exceeded the mean grip strength for girls at all ages from three to six. These differences were statistically significant, the combined probability being beyond the 1 per cent level. But it is also true that the mean height of boys is greater than the mean height of girls for this same age period. As will be shown in the following chapter, grip strength is closely related to height, so the question may be raised: Is the difference in mean grip strength between boys and girls at the preschool ages a function of the difference in height, or are the boys still superior after accounting for the amount due to the difference in height?

The method of analysis of covariance was used to study this problem, the procedure being the same as that described for the similar analysis of breathing capacity. The mean height and grip strength of each age-sex group used in this analysis is shown below:

	Number	Height Cm.	Grip Kg.
Boys			
2 years, 6 months to 3 years, 5 months	21	98.2	7.9
3 years, 6 months to 4 years, 5 months	27	104.4	9.5
4 years, 6 months to 5 years, 5 months	39	111.8	11.8
5 years, 6 months to 6 years, 5 months	26	115.4	13.1
Girls			
2 years, 6 months to 3 years, 5 months	19	95.2	6.8
3 years, 6 months to 4 years, 5 months	19	102.3	8.9
4 years, 6 months to 5 years, 5 months	25	108.4	10.1
5 years, 6 months to 6 years, 5 months	18	114.9	11.3

A separate analysis was made for each age group. The "adjusted" or reduced variances are shown below:

2 years, 6 months to 3 years, 5 months

Reduced Variance for Sexes	2.1254	1 d.f.
Reduced Variance Within Groups	1.1887	37 d.f.

F = 1.79, which is not significant for 1 x 37 d.f.

3 years, 6 months to 4 years, 5 months

Reduced Variance for Sexes	.2724	1 d.f.
Reduced Variance Within Groups	1.7364	44 d.f.

F is not significant.

4 years, 6 months to 5 years, 5 months

Reduced Variance for Sexes	11.3895	1 d.f.
Reduced Variance Within Groups	2.2307	61 d.f.

F = 5.11, which is significant between the 5 per cent and 1 per cent levels for 1 x 61 d.f.

5 years, 6 months to 6 years, 5 months

Reduced Variance for Sexes	32.0795	1 d.f.
Reduced Variance Within Groups	2.3757	41 d.f.

F = 13.50, which is significant beyond the 1 per cent level for 1 x 41 d.f.

These analyses produce the interesting finding that at three and four years of age the differences in mean strength for boys and girls when adjusted for differences in height, are not great enough to be statistically significant. At five years of age, it is highly probable that boys have a greater grip strength than girls for their height, and at six years it may be stated with considerable assurance that the girls of this preschool group are the "weaker sex."

This raises an interesting question as to the nature of, or the reason for, this difference. Is the greater strength of boys a result of participation in more strenuous types of activity, or is there a sex difference in strength which is only accentuated by the more vigorous play in which boys customarily engage? To answer such a question is beyond the limits of this study, but it may be noted that the play activities of three- and four-year-old children are very similar for both boys and girls, but that by five years and six years of age some differences in type of play may be noted. Again, it is not possible to state whether the more strenuous play produces the greater strength or the greater strength is an incentive to more

vigorous play, or whether the two are mutually operative, each helping to develop the other.

GROWTH OF INDIVIDUALS

Thirty-two children were tested in the spring of 1939 and again in the fall of the same year, four and one-half to seven months elapsing between the two sets of measurements. From these two sets of scores it was possible to compute individual increments in grip strength. Since there was some fluctuation in the length of time elapsing between tests, all increments were reduced to the amount gained per month over the period. These monthly increments are tabulated below:

Age at Initial Measurement	Number	Mean Monthly Increment, Kg.	Range of Monthly Increments, Kg.
2 years, 6 months to 2 years, 11 months	1	.30	
3 years, 0 months to 3 years, 5 months	7	.25	.06 to .70
3 years, 6 months to 3 years, 11 months	4	.29	.03 to .43
4 years, 0 months to 4 years, 5 months	8	.31	.13 to .55
4 years, 6 months to 4 years, 11 months	9	.36	.10 to .60
5 years, 0 months to 5 years, 5 months	3	.39	.29 to .52
Total	32	.32	.03 to .70

It will be noted that the individual variation is great, the increments ranging from .03 to .70 kg. per month.

The mean monthly increment of .32 would suggest that the annual increment should be approximately 3.84 kg. This is greater than the mean annual gains of 1.73 kg. for boys and 1.47 kg. for girls found in the cross-sectional material. Since the two tests were administered in the spring and the fall, this might be interpreted as indicating that greater increases in strength are made in the summer than in the winter. Evidence will be presented in Chapter XV which will lend some weight to this suggestion. On the other hand, there may be a factor of experience entering into the second testing. A third possibility, of course, is that this phenomenon is simply a fluctuation due to sampling.

Baldwin (14) analyzed a series of individual growth curves of strength of grip for school age children. He found that

> "Individual strength curves . . . are similar in irregularity

> to the breathing capacity curves. . . . In the distribution of strength curves, there is more overlapping, with marked fluctuations in increments of improvement or regression in individual strength curves than is the case in curves of height, weight, breathing capacity, sitting height, and chest girth.'' (p. 94)

The increments obtained in the present study show some irregularities, but these irregularities are much less marked than those obtained for breathing capacity.

CHAPTER XIII

RELATIONSHIP OF GRIP STRENGTH TO CERTAIN PHYSICAL AND MENTAL MEASUREMENTS

ANTHROPOMETRIC RELATIONSHIPS

Few correlations of grip strength with other measures have been reported for children below ten years of age, the most extensive series having been reported by Baldwin (14, 15). In 1921 Baldwin computed correlations of grip strength with height, weight, and breathing capacity for groups of about sixty children of each sex from seven to seventeen years of age. His subjects were drawn from the Horace Mann School of New York City. For the ages seven, eight, nine, and ten, the values obtained ranged as follows:

Strength of Right Grip With	Boys	Girls
Height	.488 to .641	.423 to .801
Weight	.641 to .796	.429 to .540
Breathing capacity	.523 to .623	.377 to .694
Strength of left grip	.709 to .866	.805 to .866

For boys the correlations of grip with weight appear to be higher and to show less fluctuation than those with height, while for girls higher correlations are found with height.

For the "genius" group of California children Baldwin (15) reported correlations over the age range seven to fifteen.

Right Grip With	Boys	Girls
Chronological age	.762	.827
Breathing capacity	.971	.849
Breathing capacity (age constant)	.934	.527

From data previously described Gates (48) reported the following correlations:

Grip Strength and	Correlations
Ossified carpal area	.25
Per cent ossification	.24
Height	.45
Weight	.40
Chest girth	.36
Lung capacity	.46
Nutrition	.14
Heart rate	—.06

Johnson (68) tested private school children three to thirteen years of age. She reported a correlation of grip with the weight/height index of .68 for the whole age range, and of .37 when age was held constant. For ninety-eight cases, she found a correlation of .77 for right grip and age.

Baldwin (14) is the only investigator who has attempted to analyze grip relationships for children below ten years of age by the method of partial correlation. From the Horace Mann data previously described, he reported the following partial correlations for ages seven to ten inclusively. The variable "held constant" is enclosed in parentheses.

	Boys	Girls
Right grip, height (weight)	—.176 to .169	.126 to .710
Right grip, weight (height)	.305 to .546	.106 to .372
Right grip, height (breathing capacity)	.019 to .475	.242 to .716
Right grip, breathing capacity (height)	.076 to .397	—.001 to .534
Right grip, weight (breathing capacity)	.331 to .668	.320 to .424
Right grip, breathing capacity (weight)	.068 to .274	.089 to .592
Height, weight (right grip)	.674 to .828	.253 to .543
Height, breathing capacity (right grip)	.603 to .744	—.075 to .607
Weight, breathing capacity (right grip)	.468 to .679	.143 to .563

The wide range of these correlations for any given combination of variables makes it difficult to draw any conclusions, but it appears that for boys the relationship between grip strength and weight is closer than between grip strength and height. For girls, the reverse would seem to be true.

At the older school ages correlational studies have been reported by Anderson (5, 6), Baldwin (14, 15), Binet and Vaschide (20), Carman (25), Harris (56), and Patrick and Rowles (94). Many other studies have been reported on the relationships of the Strength Index battery to various anthropometric relationships, but none of these has studied the single measurement of grip strength. They will not be discussed here.

In the present study Pearson product-moment correlations were computed between grip strength and certain anthropometric measurements, for the age range 2 years, 6 months to 6 years, 5 months. These values are shown in Table 5, which will be found on p. 93 in Section II.

For boys the highest correlations were found between grip strength and height (.80), breathing capacity (.80), arm length (.79), shoulder width (.78), sitting height (.77), weight (.75) and age (.74).

For girls the highest relationships were found between grip

strength and arm length (.86), height (.85), shoulder width (.85), sitting height (.83), breathing capacity (.81), age (.79), and weight (.75). It is interesting to note that the correlations for girls tend to run slightly higher than those for boys. The reverse tendency has been most commonly found by other investigators for measures of strength. The correlations in the present study tend to be somewhat higher than those reported by Baldwin, Gates, and Johnson for the same variables with elementary school children.

Correlations for grip strength with arm and forearm circumferences are relatively low (approximately .45) for both sexes, indicating that measurements over the muscles used in grip strength are not good indicators of the strength of those muscles.

Partial correlations were computed to study the interrelationships of the measurements. These are shown in Table 13.

As with breathing capacity, holding age constant reduces the correlations somewhat, the average being about .50 for boys and about .45 for girls. Holding height constant produces a much more marked effect. When height is held constant, the largest correlations for boys are with breathing capacity (.36), age (.31), and sitting height (.29). For girls the highest values are for shoulder width (.38), arm length (.31), and breathing capacity (.22).

When weight is held constant, the correlations with age are reduced to .53 for boys and .71 for girls, while the correlations with height drop to .59 for boys and .69 for girls. But when height is held constant the correlations of weight and grip strength drop to .06 for boys and .08 for girls. The values found for grip and height with weight constant are much higher than those given by Baldwin, and do not bear out his conclusion that weight is more closely related to grip strength than is height.

The relationship of height to grip strength was further investigated by computing correlations for each age-sex group. These coefficients are:

Age	Boys		Girls	
	Number	r	Number	r
2 years, 6 months to 3 years, 5 months	18	.513	22	.733
3 years, 6 months to 4 years, 5 months	27	.521	19	.648
4 years, 6 months to 5 years, 5 months	39	.669	25	.486
5 years, 6 months to 6 years, 5 months	26	.629	18	.670

These values are comparable with the correlations of .64 for boys

Table 13
Partial Correlations of Grip Strength with Selected Anthropometric Measurements for Boys (N = 110) and Girls (N = 79), 2 Years, 6 Months to 6 Years, 5 Months of Age

Grip Strength With	Constant Variable									
	Age	Height	Chest Circum-ference	Shoulder Width	Sit-ting Height	Hip Width	Fore-arm Girth	Weight	Arm Length	Elbow Width
Boys										
Age		.311	.620	.429	.477	.530				.672
Height	.531			.374	.368	.458		.445	.294	.639
Chest circumference	.423	.113								
Shoulder width	.525	.203			.337	.367				.574
Sitting height	.538	.293		.284						
Hip width	.557	.222		.257						.539
Weight	.523	.060								
Arm length (N = 91)		.169					.678			.604
Elbow width	.539	.195		.149		.204				
Breathing capacity	.536	.362								
Girls										
Age		.170	.705	.406	.377	.516				.726
Height	.529			.404	.351	.563		.606	.183	.782
Chest circumference	.378	.058								
Shoulder width	.605	.378			.477	.586				.774
Sitting height	.533	.117		.389						
Hip width	.461	.104		.269						.669
Weight	.471	.078								
Arm length (N = 60)		.314					.819			
Elbow width	.323	.069		—.025		.161				
Breathing capacity	.417	.216								

and .57 for girls found for the entire age range with age held constant, but they show some fluctuations, as might be expected with samples of this size. They tend to be somewhat higher than the values reported by Baldwin for the ages seven, eight, nine, ten, but lie within the same general range.

Multiple correlations were computed for grip strength with various combinations of anthropometric measurements as shown below:

Grip Strength With	Boys	Girls
Age, height, shoulder width	.832	.879
Height, shoulder width, hip width	.816	.874
Height, age, weight	.828	.858
Age, shoulder width	.822	.874
Height, shoulder width	.812	.874
Height, arm length	.809	.872
Arm length, forearm circumference	.796	.863
Height, age	.824	.855
Height, hip width	.814	.853
Height, weight	.803	.852
Height, chest circumference		.851
Age, weight	.821	.849
Elbow width, arm length	.795	
Age, elbow width		.816

When these multiple correlations are compared with the zero-order correlations of height and grip strength (.80 for boys and .85 for girls), it will be seen that the addition of other measurements to height produces but little increase in the size of the correlations.

Application of these correlations to the estimation of the grip strength of the individual child will be made in the following pages.

ESTIMATES OF GRIP STRENGTH FROM MEASUREMENTS OF BODY SIZE

The need for standards or tables with which to estimate the expected grip strength of an individual has been expressed by Griffitts (54). He wrote:

> "... after we find an individual's score, we are likely to want to know what his strength 'should be,' and here we run into trouble .... about all we can find in the way of norms are tables showing the average grip for children of different ages. No provision is made for making allowances for differences in sizes among children of the same age. About the best we can do is to turn to other tables and find the average of children of the same size as the child we have, and then get the average grip of children of this other age. But this procedure is unsatisfactory for general use because it assumes that the strength should be the same for children of the same size, irrespective of age." (p. 115)

> ". . . In connection with norms of such things as weight and strength, we are always confronted with another problem. Should they give actual weights or strength scores for a true sample of the population, or should they give the weights or strength scores for those who are in good condition? . . . Norms influenced by measures of weaklings will make the weaklings appear more nearly normal. And, if corrections in strength scores are made for deviations from the 'normal' weight, the final norms for strength, if soft, obese, and weak individuals are used in establishing them, will make these individuals appear more nearly normal." (p. 121)

No standards for grip strength based on anthropometric measurements have been found in the literature. McCloy (79, 80) and Rogers (103, 104) have used age and weight as the basis of their tables for estimating the strength of an individual by the Strength Index, but they have provided no separate norms for grip strength.

From the correlational analysis of the preceding pages it appears that height is the best single variable to use in estimating grip strength for boys, while arm length gave a slightly higher correlation for girls. For boys the correlation of height and grip strength was .80 and for girls .85. For girls, arm length correlated .86. However, this correlation became insignificant when height was held constant.

The addition of other variables to height raised the predictive accuracy slightly, the highest multiple correlations being found with age, height, and shoulder width; .83 for boys and .88 for girls. Age, height, and weight gave .83 and .86, respectively; age and weight .82 and .85; age and height .82 and .86.

Bearing in mind the dual considerations of accuracy and simplicity of administration, it seemed that age and height offered the most satisfactory combination for use in practical school situations. The accurate determination of weight requires that the child shall be undressed and the use of weight involves the problem of over- and underweight which was discussed by Griffitts above. The shoulder width measurement is one of the more difficult anthropometric measurements to take accurately. Age, while adding little to the predictive value of height, is easy to obtain and is useful in increasing the accuracy of the estimates of the grip strength of those children who are at the extremes of the height range for their age.

From the intercorrelations of grip strength, height, and age in years and half years, the following multiple regression equations were obtained:

Boys: Grip Strength, kgs. = .1836 (Height, cm.) + .7543 (Age, years and half years) — 12.3746 (R = .824)

Girls: Grip Strength, kgs. = .1694 (Height, cm.) + .3751 (Age, years and half years) — 10.1093 (R = .855)

From these regression equations Table 14 was computed. This table makes it possible to estimate the grip strength of a preschool child, given his age and height. The standard error of estimate for boys is .80 kg., which is 7.3 per cent of the mean. For girls it is .55 kg., or 5.8 per cent of the mean.

The Grip Quotient

The expected grip strength for age and height was determined for each of the subjects in the present study. The actual grip strength multiplied by 100 was divided by the expected grip strength to give the grip quotient (GQ).

The range of these grip quotients was from 63 to 139, and the standard deviation of the entire distribution was 12.4. Frequency distributions of these quotients for the separate age-sex groups are shown in Table 15.

Since the distribution of grip quotients for all of the ages combined is essentially normal in form, the statistically "normal" range for this group of children may be stated in terms of the standard deviation. Thus, for one standard deviation on either side of the mean the range is from 87.4 to 112.2, for two standard deviations 75.0 to 124.6, and for three standard deviations 62.6 to 137.0. Only one child lies more than three standard deviations above the mean and no child is more than three standard deviations below. Five children are more than two standard deviations above the mean and seven are more than two standard deviations below.

COMPARATIVE STRENGTH OF RIGHT AND LEFT HANDS

Heinlein (58) tested the grip strength of sixty children, four to twelve years of age, over a period of five years. She described her subjects as "unselected normals," and tested them once each year. She found that 61.7 per cent were consistently "right handed" in all tests, 3.3 per cent were consistently "left handed," and 35.0 per cent inconsistent. She reported a "tendency toward improvement with each hand with increase in chronological age in all three handedness divisions," (p. 95) but found "no consistent tendency toward increase or decrease in difference between the two hands." (p. 95)

Table 14
Estimates of the Grip Strength in Kilograms from Height in Centimeters and Age in Years for Boys and Girls from 2 Years, 6 Months to 6 Years, 5 Months of Age

Height	Age							
	2 Years, 6 Months to 2 Years, 11 Months	3 Years, 0 Months to 3 Years, 5 Months	3 Years, 6 Months to 3 Years, 11 Months	4 Years, 0 Months to 4 Years, 5 Months	4 Years, 6 Months to 4 Years, 11 Months	5 Years, 0 Months to 5 Years, 5 Months	5 Years, 6 Months to 5 Years, 11 Months	6 Years, 0 Months to 6 Years, 5 Months
	Boys							
90	6.0	6.4	6.8	7.2				
91	6.2	6.6	7.0					
92	6.4	6.8	7.2	7.5				
93	6.6	7.0	7.3	7.7				
94	6.8	7.1	7.5	7.9	8.3			
95	7.0	7.3	7.7	8.1	8.5			
96	7.1	7.5	7.9	8.3	8.6			
97	7.3	7.7	8.1	8.5	8.8			
98	7.5	7.9	8.3	8.6	9.0	9.4		
99	7.7	8.1	8.4	8.8	9.2	9.6		
100	7.9	8.2	8.6	9.0	9.4	9.8	10.1	10 5
101	8.1	8.4	8.8	9.2	9.6	9.9	10.3	10.7
102	8.2	8.6	9.0	9.4	9.7	10.1	10.5	10.9
103	8.4	8.8	9.2	9.6	9.9	10.3	10.7	11.1
104	8.6	9.0	9.4	9.7	10.1	10.5	10.9	11.2
105	8.8	9.2	9.5	9.9	10.3	10.7	11.1	11.4
106			9.7	10.1	10.5	10.9	11.2	11.6
107			9.9	10.3	10.7	11.0	11.4	11.8
108			10.1	10.5	10.8	11.2	11.6	12.0
109			10.3	10.7	11.0	11.4	11.8	12.2
110			10.5	10.8	11.2	11.6	12.0	12.3

Grip strength for boys = .1836 Height + .7543 Age — 12.3746

111			11.0	11.4	11.8	12.2	12.5
112			11.2	11.6	12.0	12.3	12.7
113			11.4	11.8	12.1	12.5	12.9
114			11.6	12.0	12.3	12.7	13.1
115			11.8	12.1	12.5	12.9	13.3
116				12.3	12.7	13.1	13.4
117				12.5	12.9	13.3	13.6
118				12.7	13.1	13.4	13.8
119				12.9	13.2	13.6	14.0
120				13.0	13.4	13.8	14.2
121					13.6	14.0	14.4
122						14.2	14.6
123						14.4	14.7
124						14.5	14.9
			Girls				
85	5.2	5.4	5.6				
86	5.4	5.6	5.8				
87	5.6	5.8	5.9				
88	5.7	5.9	6.1				
89	5.9	6.1	6.3				
90	6.1	6.3	6.4	6.6			
91	6.2	6.4	6.6	6.8			
92	6.4	6.6	6.8	7.0			
93	6.6	6.8	7.0	7.1			
94	6.8	6.9	7.1	7.3			
95	6.9	7.1	7.3	7.5	7.7		
96	7.1	7.3	7.5	7.7	7.8		
97	7.3	7.5	7.6	7.8	8.0		
98	7.4	7.6	7.8	8.0	8.2		
99	7.6	7.8	8.0	8.2	8.3		
100	7.8	8.0	8.1	8.3	8.5	8.7	
101	7.9	8.1	8.3	8.5	8.7	8.9	
102	8.1	8.3	8.5	8.7	8.9	9.0	
103	8.3	8.5	8.7	8.8	9.0	9.2	

Table 14 (continued)

Height	Age							
	2 Years, 6 Months to 2 Years, 11 Months	3 Years, 0 Months to 3 Years, 5 Months	3 Years, 6 Months to 3 Years, 11 Months	4 Years, 0 Months, to 4 Years, 5 Months	4 Years, 6 Months to 4 Years, 11 Months	5 Years, 0 Months to 5 Years, 5 Months	5 Years, 6 Months to 5 Years, 11 Months	6 Years, 0 Months to 6 Years, 5 Months
104	8.4	8.6	8.8	9.0	9.2	9.4		
105	8.6	8.8	9.0	9.2	9.4	9.6	9.7	9.9
106	8.8	9.0	9.2	9.3	9.5	9.7	9.9	10.1
107	9.0	9.1	9.3	9.5	9.7	9.9	10.1	10.3
108		9.3	9.5	9.7	9.9	10.1	10.2	10.4
109			9.7	9.9	10.0	10.2	10.4	10.6
110			9.8	10.0	10.2	10.4	10.6	10.8
111			10.0	10.2	10.4	10.6	10.8	10.9
112			10 2	10.4	10.6	10.7	10.9	11.1
113			10.3	10.5	10.7	10.9	11.1	11.3
114				10.7	10.9	11.1	11.3	11.5
115				10.9	11.1	11.2	11.4	11.6
116				11.0	11.2	11.4	11.6	11.8
117				11.2	11.4	11.6	11.8	12.0
118				11.4	11.6	11.8	11.9	12.1
119					11.7	11.9	12.1	12.3
120					11.9	12.1	12.3	12.5
121					12.1	12.3	12.5	12.6
122						12.4	12.6	12.8
123						12.6	12.8	13.0
124						12.8	13.0	13.1
125						12.9	13.1	13.3

Grip strength for girls = .1694 Height + .3751 Age — 10.1093

Table 15
Distribution of Grip Quotients for 198 Children Between the Ages of 2 Years, 6 Months and 6 Years, 5 Months

Grip Quotients	2 Years, 6 Months to 3 Years, 5 Months		3 Years, 6 Months to 4 Years, 5 Months		4 Years, 6 Months to 5 Years, 5 Months		5 Years, 6 Months to 6 Years, 5 Months		Total
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	All Cases*
135 to 139			1			1			2
125 to 129	1				1		1		3
120 to 124	2			1		1			4
115 to 119			1	4	2		1		8
110 to 114	4	3	4	1	8	3	2	1	26
105 to 109	2	2	2	1	3	2	3	2	17
100 to 104	5	3	3	3	7	5	5	3	34
95 to 99	1	1	7	4	8	5	7	6	39
90 to 94	2	4	4	3	7	4	3	5	32
85 to 89	2	3	2	2	1	3	2	1	16
80 to 84	1	1				1			3
75 to 79	1	1	1		2		2		7
70 to 74		1			1	1			3
65 to 69	1		1		1				3
60 to 64			1						1

* Mean = 99.8; S.D. = 12.4.

Johnson (68) analyzed the data obtained on children three and one-half to thirteen years of age, previously described, for "handedness" tendencies and concluded:

> "There are few young children who show consistent superiority of one hand in consecutive trials and in annual retests in the dynamometer test. There is a marked tendency toward ambidexterity or right-handedness with increasing chronological age." (p. 77)

Mead (86) compared 430 children, six to eighteen years of age, in the public schools of Caldwell, New Jersey with 430 children in the Indiana School for Feeble-Minded Youth. He noted that the divergence between the strength of the two hands tended to increase with age. He found a difference in favor of the right hand at all ages for normal children, but for the feeble-minded the strength of the two hands was more nearly alike and at some ages the left was stronger than the right.

Smedley (108) believed that:

> "on the whole, the brightest are more decidedly unidextrous than are the dull pupils, and they in turn are more decidedly unidextrous than are the pupils of the John Worthy School [a house of correction]." (p. 91)

Woo and Pearson (130) analyzed 7,000 records of grip strength taken from the files of Sir Francis Galton. They reported:

> "Absolute grip of the stronger hand rises from about 11.6 lbs. at 6.5 years of age to about 84 lbs. at 32 years, and falls to 56 lbs. at 79 years. But the differences of right-handed and left-handed grips remain about 3.6 lbs. through all age groups." (p. 168)

In the present study the second best of the six days' scores for each hand were tabulated. For 66.0 per cent of the subjects the right grip exceeded the left grip by more than .2 kg. For 18.5 per cent the left grip exceeded the right grip by more than .2 kg. And for 15.5 per cent there was .2 kg. or less difference between the two hands. The number of children in each category for each age group is shown below. Separate X^2 tests for each age group and for all ages combined showed no significant differences in the relative numbers of boys and girls in each category. In the tabulation below the two sexes are combined.

Age	Right Exceeds Left by More Than .2 kg.		Right = Left Within .2 kg.		Left Exceeds Right by More Than .2 kg.	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
2 years, 6 months to 3 years, 5 months	17	42.5	9	22.5	14	35.0
3 years, 6 months to 4 years, 5 months	25	53.2	16	34.1	6	12.7
4 years, 6 months to 5 years, 5 months	54	79.4	7	10.3	7	10.3
5 years, 6 months to 6 years, 5 months	36	80.0	5	11.1	4	8.9

The per cent of cases for whom the right hand is stronger than the left increases with increasing age, 42.5 per cent of the children falling in this category at three years as compared with 80.0 per cent at six years. At three years of age, 35.0 per cent of the subjects have left hands which are stronger than the right, while 22.5 per cent of them show no difference between the two hands. But at four years, only 12.7 per cent are "left-handed," while 34.1 per cent show no difference between the two hands. The proportion of children falling in each category is about the same at five years as it is at six. Approximately 80 per cent of the children are "right-handed" at these ages, while about 10 per cent are "left-handed," and for 10 per cent there is no difference between the two hands.

These figures support Johnson's finding of a "marked tendency toward . . . right handedness with increasing chronological age," but the tendency toward ambidexterity which she described is not noted in the present data. On the contrary, the number of children showing no marked difference between the two hands tends to decrease with age.

The average difference in amount of grip strength between the two hands increases from about .5 kg. at three years to about 1.0 kg. at six years. The mean differences and their relationship to the actual strength of the strongest hand for the eight age-sex groups are tabulated below:

Age	Boys		Girls	
	Average Difference, kg.	Per Cent of Mean Strength	Average Difference, kg.	Per Cent of Mean Strength
2 years, 6 months to 3 years, 5 months	.543	6.9	.595	8.7
3 years, 6 months to 4 years, 5 months	.688	7.2	.690	7.7
4 years, 6 months to 5 years, 5 months	.788	6.7	.976	9.7
5 years, 6 months to 6 years, 5 months	1.062	8.1	1.047	9.3

The average absolute difference in strength between the hands increases with age, but this difference remains roughly proportional to the mean strength of the stronger hand throughout this age period. The X^2 test shows no significant differences among the percentages of mean strength.[11]

This finding is in agreement with Mead's statement that normal public school children show an increasing divergence between the two hands with increasing age, but is in contradiction to Heinlein's report of "no consistent tendency toward increase or decrease in difference between the two hands," and Woo and Pearson's findings of a constant difference of 3.6 pounds (1.6 kg.) at all ages.

Thirty-two children were tested in the spring and again in the fall. The scores for the two hands for each individual were compared for the two testings. In the following tabulation *R* indicates that the right hand exceeded the left by more than .2 kg., *L* indicates that the left hand exceeded the right by more than .2 kg., and 0 indicates that the difference between the two hands was less than .2 kg.

Spring	Fall	Age at Initial Testing: 2 Years, 6 Months to 3 Years, 5 Months	3 Years, 6 Months to 4 Years, 5 Months	4 Years, 6 Months to 5 Years, 5 Months
R	R	1	5	10
L	L		1	
O	O	1	1	1
L	R	3		
L	O	1		
O	R	1	3	
R	O	1	2	
R	L			1
Total		8	12	12

[11] There is no contradiction between this finding and the one given above relative to the development of hand dominance in strength. The first finding deals with the numbers of subjects showing certain types of differences, and the second deals with the absolute amount of those differences.

It may be noted that for the three-year-old group, two children (25.0 per cent) are consistent on both tests, and at four years seven children (58.3 per cent) are consistent. At five years eleven children (91.7 per cent) are consistent on both tests, and ten of these show a consistent superiority with the right hand.

The number of cases at each age is too small to permit generalization, but there appears to be a tendency toward increasing consistency with increasing chronological age. Over the entire age range, it may be noted that eight cases show shifts which indicate that the strength of the right hand is increasing more rapidly than that of the left (*L* to *R*, *O* to *R*, and *L* to *O*), while four show shifts in the other direction (*R* to *L*, and *R* to *O*).

Only one child of the thirty-two was consistently superior with the left hand. She is considered by her parents and teachers to be "left-handed," and uses the left hand consistently in eating, drawing, and other uni-manual activities.

The implication of Smedley's statement that the brightest children are more unidextrous than the dull pupils is that ambidexterity is associated with dullness. This hypothesis was not tested in the present study. Since the IQ range for these subjects was from 85 to 191, with only one child falling below 100, there were no "dull" subjects available.

MENTAL RELATIONSHIPS

Porter (96) in 1892 made the first approach to the problem of the relationship existing between grip strength and mental ability. He studied a series of anthropometric measurements, including grip strength, taken on 18,059 boys and 16,295 girls between the ages of six and seventeen in the St. Louis schools. He recommended that:

> "no pupil whose physical development varies more than one probable deviation from the weight, etc. [including grip strength] of the mean pupil of his height, in a class which his mental output would otherwise entitle him to enter, shall be admitted to that class, unless with the approval of a medical expert, . . . who shall testify that the pupil's strength will be equal to the strain." (p. 348)

In 1897, MacDonald (82) tested the grip strength of 548 girls and 526 boys of school age with the Collin dynamometer. He classified them as bright, average, dull, and unruly, and computed the mean grip strength of each group. He concluded:

> "There seems to be no relation between strength of hand and mental ability. Strength of hand depends more upon sociological conditions; that is, those children who through force of circumstances are compelled to work outside of school hours and are sometimes kept out of school for this purpose, naturally develop their strength. The percentage of dullness among such children is liable to be large, and this may account for the dull boys having comparatively greater strength of hand grasp." (p. 1005)

However, his groups differed markedly as to age, the dull groups being the oldest, which fact might account for their greater grip strength.

Binet and Vaschide (20) tested forty-two boys from ten to fourteen years of age, and arranged them in four groups according to their strength of grip. The *ordre intellectuel* was assigned by the teacher and a test of number memory (in addition to a number of motor tests) was given. They concluded:

> "In all the tests in our table, the average of the first group is greater than the average of the last group; or, again, we may say that the average of the first two groups is greater than the mean of the last two groups.
>
> "What does this regular decrease in the series signify? It means that all the tests are sufficient to divide the pupils into two groups: those who are strong and those who are weak; that is, with one test of the dynamometer one is able to divide the pupils into two groups in which the first are superior to the second not only in strength but in vital capacity, . . . number memory, etc.
>
> ". . . We find a relationship, though not entirely clear and subject to some irregularities in details, between the strength on the dynamometer and . . . the reaction time . . . the intellectual rank." (p. 149-150)[12]

In 1899 Carman (25) used the Collin dynamometer to test 756 boys and 751 girls, ages ten to nineteen in the public schools of

[12] ". . . dans toutes les épreuves de notre tableau, le résultat moyen du premier groupe est supérieur au résultat moyen du dernier groupe; ou encore, on peut dire que le résultat moyen des deux premier groupes est supérieur au résultat moyen des deux derniers groupes. . . .

"Que signifie cette décroissance régulière des séries? Elle signifie que toutes les épreuves . . . sont suffisantes pour répartir les élèves en deux groupes: celui des forts et celui des faibles; ainsi, avec une épreuve du dynamomètre, on peut diviser les élèves en deux groupes, dont le premier sera supérieur au second non seulement comme force dynamomètrique, mais en moyenne comme capacité vitale, . . . mémoire des chiffres, etc. . . .

". . . nous trouvons une corrélation analogue, mais cependant moins nette et sujette à quelques irrégularités de détail, entre la force au dynamomètre et . . . les temps de réaction, . . . l'ordre intellectuel." (p. 149-150)

Saginaw, Michigan. The children were rated as bright or dull in mathematics by their teachers. She concluded that "bright boys and girls are . . . in general . . . stronger," (p. 397-398) but gave no figures to bear out her conclusion.

Christopher (28) and Smedley (108) tested the relationship between grip strength and mental ability by selecting children eleven and twelve years of age in different school grades. They found that the mean strength of the children in the higher grades was greater than that of those in the lower grades, and concluded: "In general there is a distinct relationship in children between physical condition and intellectual capacity, the latter varying directly as the former." (28, p. 72)

Berry and Porteus (18) reported correlations between grip strength and mental age from the Porteus maze test for 1,248 children, six to thirteen years of age, and between grip strength and mental age from the Binet test for 894 cases. Their correlations by one year age groups range from negative values to .60, the average of all correlations being about .30.

Garrison and Pullias (47) tested forty-five children in grades four to eight at the demonstration school of George Peabody College. They found that for both IQ and grip strength all scores fell above the 90th percentile on "appropriate tables," which they did not identify.

Jewish children classified as above 135 IQ, between 90-110 IQ and below 65 IQ were studied by Hollingworth and Taylor (62). They used forty-two children in each group matched as to age (nine to eleven years) and sex. They reported no means but concluded:

> "Children testing in the highest one per cent of human intelligence have superior strength of grip, as a group. . . . Intellect cannot, however, be reliably inferred from grip, nor grip from intellect, . . . as there is overlapping upon medians in strength between groups of children chosen from opposite extremes for intellect." (p. 236-237)

A similar study was made by Monahan and Hollingworth (90). They tested forty-five children with IQ's from 135-190 and forty-five with IQ's of about 100 (average age 135 months). A difference of 1.6 pounds, with a probable error of .48 pounds, was found in favor of the high IQ group. This was considered by them to support the conclusion: "Intellectually gifted children excel children

from the regular classes in grip of hand . . . which exemplifies performance not involving body weight.'' (p. 95) However, the mean weight of their gifted group was 88 pounds and that of their controls 81, a difference in size which might easily account for the difference found in strength.

Kiefer (71) compared the grip strength of ninety-five children, eight to twelve years of age, having IQ's of 115 or above with the strength of a similar group of children with ''normal'' intelligence. She gave no data, but reported: ''With very few exceptions the differences are negligible between experimental and control groups.'' (p. 369)

Correlations ranging from .05 to .20 between grip strength and various measures of mental ability were reported by Gates (48) for the junior primary and fourth grade subjects previously described.

Baldwin (15) compared the grip strength of the ''geniuses'' of Terman's California study with the average grip strength of a control group of Oak Park (Illinois) children, and reported that the ''geniuses'' were superior in right grip over the control group. However, he found an error in the dynamometer used, which necessitated ''correcting'' the California data by an average amount of 2.17 kg. for boys and 2.33 kg. for girls, which throws some doubt on the exactness of his findings.

Johnson (68) reported correlations between grip strength and mental age for ninety-eight children from three to thirteen years of age as follows:

Grip, Mental Age	.71
Grip, Mental Age (Chronological Age)	.13
Grip, Mental Age (Weight-Height Index)	.45
Grip, Mental Age (Weight-Height Index, C.A.)	.03

The partial correlations would seem to indicate that any apparent relationship between grip strength and mental age is largely a function of chronological age or body size.

Hoefer and Hardy (61) classified 343 children in grades three and four of the Joliet (Illinois) Public Schools as ''accelerated'' or ''retarded'' with reference to development of grip strength over a three year period.

> ''The rate of improvement for right grip . . . was the ratio of each child's actual gain during the period of three years to his expected gain. . . . The expected gain was the normal

> rate for his age and sex, derived from standard tables [not identified].'' (p. 383)

They concluded: ''Those classed as 'accelerated' in right grip show a consistent tendency in all three school subjects to surpass those classed as 'retarded.' '' (p. 384) The differences shown, however, are in all cases very slight.

Using dynamometers of their own devising, Gilbert (49, 50) reported that no differences in strength were found among bright, average, and dull students, while Bagley (12) reported ''a decidedly inverse relation between mental ability, as indicated by class standings, and motor ability as indicated by the dynamometer records.'' (p. 200)

From these studies it is impossible to draw any clear cut conclusion as to the relationship existing between grip strength and mental ability, since positive relationships, negative relationships, and a complete lack of relationship have all been reported. Considering all the evidence, however, the tentative conclusion may be drawn that the correlation between mental ability and grip strength is either zero or very slightly positive.

In the present study mental age as determined by the 1937 Revision of the Stanford-Binet Intelligence Test was studied in relation to grip strength for 103 boys and 66 girls between the ages of 2 years, 6 months and 6 years, 5 months. For the boys, mental age and grip strength correlated .56, and for the girls .71. When chronological age was held constant these correlations dropped to —.06 for boys and —.03 for girls. This would indicate that the apparent relationship between mental age and grip strength is only a function of the relationship between chronological age and mental age. Similar results were obtained with height as the variable held constant. The correlations were .09 for boys and .06 for girls.

Using intelligence quotients and grip quotients for both sexes combined, a correlation of —.06 indicated that the two variables have no relationship to each other.

There is no evidence in the present study to support the view that grip strength is related to mental ability. As was mentioned in the discussion of breathing capacity and mental ability, it is possible that the superior mental ability of the subjects used may have been a factor in determining the ease with which the technique of performing the grip strength test was learned. It is possible that children of this age range from lower levels of mental ability might not succeed in mastering the test.

CHAPTER XIV

SUMMARY

A number of problems related to the grip strength of preschool children have been investigated in the preceding chapters. The construction of a dynamometer, administration of the test, reliability and variability, group means, physical and mental relationships, sex differences, comparative strength of the two hands, and individual growth have all been discussed. It may be desirable to summarize the principal findings before proceeding to a discussion of the health implications of grip strength tests for preschool children.

A dynamometer suited to the size, ability, and interest of preschool children was constructed. Several procedures for administering the test of grip strength to preschool children were evaluated. (1) Individualized testing was found preferable to group testing. (2) Grasping the dynamometer with the palm of the hand facing upward and the elbow slightly flexed was the position selected. (3) Three trials with each hand appeared to be the optimum number to be given at one testing. (4) The second best of the scores made by the stronger hand in six days of testing was selected as the final score to be used for each individual.

Following the standardized procedure the test was administered to 202 preschool children between the ages of 2 years, 6 months and 6 years, 5 months.

The reliability of the test scores for each hand was investigated by comparing the best score made on the odd days with the best score made on the even days from six days of testing. Correlations of approximately .90 were obtained for the separate age-sex groups.

Age means for grip strength were determined for boys and girls from three to six years of age. These means are higher than any previously reported at these ages, but are consistent with comparable means for the older ages.

An analysis of the coefficients of variation indicated that the grip strength of preschool children is no more variable than that of children between six and eighteen years of age.

Boys were found to have greater grip strength than girls at all

ages from three to six. When the effect of differences in height was eliminated, the boys were still stronger than the girls at ages five and six.

Differences between the strength of the right and left hands were discussed both as to amount and as to the number of children exhibiting greater strength with the right hand or the left hand at each age.

Data on individual growth in grip strength were presented for those children tested in the spring and again in the fall.

The relationship of grip strength to thirteen anthropometric measurements was studied using zero order, partial and multiple correlations. Height was found to have the highest relationship to grip strength at this age level.

No relationship was found between grip quotients and intelligence quotients as determined by the 1937 Revision of the Stanford-Binet Intelligence Test.

Tables for estimating the grip strength of an individual from height and age were prepared. Actual grip strength multiplied by 100, divided by the expected grip strength from these tables, was termed the Grip Quotient (GQ).

The pertinent research on children in the first decade of life was reviewed under each of the topics treated and comparisons drawn between the findings of the present study and those of other investigators.

Section IV

HEALTH RELATIONSHIPS

CHAPTER XV

HEALTH DURING THE SCHOOL YEAR AS RELATED TO BREATHING CAPACITY AND GRIP STRENGTH

BREATHING CAPACITY IN HEALTH AND DISEASE

Ever since Hutchinson (64) published his study of the uses of the spirometer in 1852 the relations existing between breathing capacity and certain conditions of health and disease have been matters both of speculation and investigation. That no doubt existed in Hutchinson's mind as to the value of spirometer readings in clinical work is shown by the following quotation:

> "This marks the value of the Spirometer—the broad difference between the healthy volume of expired air and the limited volume caused by disease generally, and particularly by thoracic disease. . . . It may be safely said, that all thoracic or abdominal diseases, as tumours or acute inflammation, or infiltration of fluid or the presence of solid matter in the respiratory organs, or bordering upon the parts comprising the thoracic cavities, immediately and for so much diminishes the breathing movement, and hence the vital capacity. Moreover, everything affecting the hard parts, as disease of the spine or ribs, whether angular or lateral curvature or the stoop produced by vocation or age, or by any disease whatsoever, is manifested by the measure of the vital capacity through the Spirometer. Likewise, whatever prevents the free ingress of air into the lungs, be the same organic or functional, as asthma, emphisema, bronchitis, or phthisis pulmonalis, is shown by the Spirometer.
>
> ". . . If the vital capacity should be 230, and we find it 154, as certain as that 230 is not 154, just so certain is it that some abnormal cause exists, to produce this difference of 76 cubic inches. Then follows the question, What is the cause of this difference? Collateral observations and the history of the case must guide us: our deduction may be wrong, i.e., it may not proceed from the cause to which we have attributed it; nevertheless, 230 is not 154, and we must look again for another cause, and though we never find the cause, yet 230 is not 154. . . . Can a man breathe according to our table, and have phthisis pulmonalis? We have never seen it; and we have seen more than 600 phthisical persons breathe into the Spirometer. Some persons have said the contrary; but was there phthisis? How often has it been said, that a person has phthisis, who had not phthisis? The Spirometer has stood as a test in the Hospital

> for Consumption; and by their Report, p. 26 (Med. Chir. Trans. vol. 29, p. 221, par. 173) there is a difference between health and disease of 33 per cent, and the authors of that Report add, 'That the Spirometer gives distinct indications, at an early period of the malady, and that these indications become more obvious, in proportion to the progress of the disease.'' (p. 11-12)

From this pioneer study has stemmed an immense body of literature relating both to general physical condition and to specific diseases. The clinical literature has been competently reviewed by Myers (90), by Lemon (74), and more recently by Thomas (116). No attempt will be made to repeat their efforts. Instead, only those studies dealing specifically with children will be discussed, supplemented by a few at the older ages in areas for which no studies on children are available.

Breathing Capacity as a Measure of General Physical Condition

There have been numerous opinions expressed concerning the relationship of breathing capacity to general physical conditions. Moreover, there have been a few experimental attempts to determine precisely the relationship using nonpathological subjects showing varying degrees of ''healthiness.'' That the problem is a complex one was indicated by Wells (123):

> ''Functional tests become more difficult the nearer the subject approaches to perfect health. A crude test is sufficient to prove that a man is dead; the evidence of failing function abound in the advanced stages of disease; but to determine the condition of an athlete is not easy. For the human organism is so complicated, a dynamic equilibrium of so many varying factors, that the significance of small departures from the expected responses must always be questionable. In the first place, what is normal? How do we know what to expect? No two responses are ever exactly alike. The subject is changing continuously. Obviously the normal is an ideal, a statistical concept, and a given departure from the normal may be healthy in one circumstance and unhealthy in another.'' (p. 46)

Opinions based on clinical observations and inference concerning the value of breathing capacity as a functional test of health status have been expressed by Beyer (19), Smedley (108), Hastings (57), Pyle (99), Affleck (2), Young (131), Dreyer and Hanson

(38), Myers (90), Rogers (103, 104), McCloy (78, 79), and Van Dalen (120). They may be summarized briefly.

Beyer, in 1896, studied the influence of exercise on the growth of U. S. Naval cadets. He stated: "A high vital index [breathing capacity divided by height] is deemed an attribute of perfect training." (p. 84)

> Smedley noted that "the great breathing capacities of the boys who were in training for football and the girls who played basketball were in strong contrast with those who took little physical exercise, which suggests that vital capacity increases and decreases with the amount of one's activity, and so, in connection with size, is an index of the rate of metabolism." (108, p. 60-1)

Hastings believed that of the series of physical measurements which he studied, "trunk dimensions, chest expansion and lung capacity are most representative of vitality." (57, p. 29) Pyle urged the use of breathing capacity, expressed as the vital index, as "one of the most significant of the physical measurements," and added that "children showing up poorly in vital capacity should have their cases further examined. In many cases it will be found that they need more exercise, particularly of a type that will develop the chest, but any vigorous outdoor exercise will be beneficial." (99, p. 41-42)

Affleck (2) attempted to set up minimum physical standards for children of school age based on Hastings' norms, and urged that physical education programs be adapted to the individual differences found in breathing capacity and other physical measurements.

Young contributed a chapter on "Hygiene of the School Age" to Abt's *Pediatrics* in which she recommended the use of the vital index to determine "whether the pupil has a lung capacity adequate for his body." (131, p. 944)

> Dreyer and Hanson stated: "As a result of examination of a large number of apparently healthy people who, from mode of life or occupation, should belong to Classes A, B, or C, respectively, it can safely be stated that if a person is found to have as much as 10 per cent less vital capacity than is normal for his class, it is *probable* that he is suffering from some health depressing condition, and if he is as much as 15 per cent below the normal limit it is *practically certain* that he is abnormal in this respect." (38, p. 19)

Myers summarized the literature on breathing capacity and con-

cluded: "Contrary to fairly recent teaching, it is apparently a test of physical fitness only in so far as the heart or lungs are involved." (90, p. 71)

When Rogers (103) revived the Intercollegiate Strength Test in 1925 and used it as the basis for his physical fitness index, he included breathing capacity in the test battery. McCloy (80) and Van Dalen (120) have pointed out that breathing capacity is not a test of strength and should not be included in this battery of tests.

In 1936, McCloy (78) discussed the use of breathing capacity in the appraisal of physical status and wrote:

> "The breathing capacity has long been used as one measure of physical status. The validity of the crude measurement as a measure of physical fitness, however, has not been very well established. At the present time the use of breathing capacity as a valid and effective measurement of physical status partakes as much of the nature of a problem as of that of a determined standard." (78, p. 99)

In 1938 he wrote further:

> "In the light of our present knowledge it would seem that breathing capacity should be measured as a routine under conditions that will insure accuracy of measurement, and that norms for the individual should be determined as accurately as possible from a number of significant variables. All children whose breathing capacity is as much as 10 per cent below this standard should be carefully examined by a physician and put upon a regimen calculated to bring the individual up to normal. These records should be available in terms of percentages of the norm of the time, and should thus be made available to the family physician and others who desire to compare present status with past performance." (79, p. 87-88)

Attempts to bring forward objective evidence as to the relationship of breathing capacity to general health status in subjects within the range of normality are few in number. Gates (48) asked five teachers to rate their pupils (previously described) as to "physical vigor." The combined rating correlated .22 with breathing capacity.

In 1927 Turner (117) compared eighteen students at Wellesley college whose breathing capacity was 15 per cent below the norm (her own norms) with twenty-six who were 15 per cent above the norm. She found that the low breathing capacity group were more subject to dyspnea, tended to choose the quieter sports, and were

somewhat underweight; while the high breathing capacity group contained only one girl subject to dyspnea, their weights were "normal," and they preferred the more vigorous sports. The examining physicians had no comments but good ones to make concerning the high breathing capacity group, while the comments concerning the low group contained such statements as "a little down," "not robust, ptosis," and "advise restricted exercise." Turner wrote:

> "In general appearance there is a difference between the two groups. One can usually tell to which group an unknown student belongs before she gives her name. The students of high vital capacity are much more 'fit' than those of low capacity." (117, p. 606)

In a second study made on Mt. Holyoke students Turner (118) obtained similar findings. She concluded:

> "By whatever test this low vital capacity group was tried out, by the test of general health, of academic or social success, it appears that it was truly at a disadvantage. There is thus the indication that vital capacity is a measurable function of significance in the general picture of the young women whose relative success in the field of health one is anxious to rate fairly." (p. 945)

In 1936, Cureton (31) attempted to analyze breathing capacity as a test of condition. Using Rogers' original strength test data on 210 Montclair High School boys, 12 years, 8 months to 19 years, 9 months of age, he analyzed them by the method of path coefficients. The multiple correlation of breathing capacity with age, height, weight, grip strength, back strength, leg strength, and arm strength was .85. The predictive value of these variables is therefore 71.6 per cent. Cureton stated: "The bulk of vital capacity is due to size as contributed through the height and weight factors. A total of 75.15 per cent relatively of vital capacity is accounted for by these two items alone." (p. 91) However, it should be pointed out that since all of the factors together had a predictive value of 71.6 per cent, his data support only the finding that 75 per cent of this amount, or 54 per cent of breathing capacity, was "due to size as contributed through the height and weight factors." He wrote further:

> "The possibility of a condition factor of the circulatory-respiratory type affecting vital capacity is rather slight when the following facts are studied:

> "a. That height and weight contribute such a large proportion and that these are uncorrelated with the circulatory-respiratory measures.
>
> "b. Likewise, age is uncorrelated with the circulatory-respiratory measures, therefore the possibility of the age contribution being due to such a condition is slight.
>
> "c. Likewise, strength is uncorrelated with the circulatory-respiratory measures. . . ." (p. 91-92)

From such considerations he concluded:

> "The evidence has been examined in the literature for vital capacity as a test of condition. It is a reflection predominantly of size as indicated principally through surface area, height, weight, or chest girth . . . In any case of using vital capacity as a test of condition, the procedure should be to correct for body size by using a regression equation of the score form as derived to fit data of the type to which it is being applied. The residual or difference between the actual vital capacity and the predicted should be used to rank subjects." (p. 92)

Breathing Capacity as Related to Specific Diseases

Investigations on the uses of breathing capacity as a clinical instrument in the diagnosis and prognosis of diseases have come principally from the medical profession. That opinion concerning the value of the test is not unanimous is indicated by the following quotation from Moersch (88), who has had wide experience with the test in routinely measuring the breathing capacity of surgical patients at the Mayo Clinic.

> "Many investigators wish to discard the spirometer because of the difficulty in interpreting the readings. Furthermore they advance the argument that even when the readings are interpreted correctly, they do not determine the nature or even the existence of disease. On similar grounds there would be no justification for the recording of temperature, pulse rate or number of leukocytes. As a reduced vital capacity warns us that disease is present, especially in the heart and lungs, the use of the spirometer is as justifiable as that of the thermometer, blood pressure apparatus, or blood counting chamber." (88, p. 130)

Tuberculosis.—In 1922, Stewart and Sheets (113) recorded the breathing capacities of eighty-nine boys and seventy-eight girls, six to fifteen years of age, at Lymanhurst and Trudeau Schools for Tuberculous Children. These suspected cases of tuberculosis showed

deviations that were from 0 to 25 per cent below Stewart's norms, but a few exceeded the norm. Stewart and Sheets wrote:

> "On repeated examinations of individuals suspected of having tuberculosis there should be very little constant deviation in vital capacity below previous determinations. The occurrence of any permanent or progressive diminution in the vital capacity below previous records will give immediate clue to the development or extension of pathological processes within the chest. . . . Repeated measurement of the vital capacity . . . is of prognostic value. A progressively decreasing vital capacity indicates the presence of an active and spreading lesion, whereas with an increasing or stationary vital capacity, the indications are the lesion present is either quiescent or is subsiding." (p. 257)

In 1926 Stewart (112) continued the study, using 248 children from the Lymanhurst School. The children ranged from 103 to 153 cm. in height. At admission to the school deviations from normal breathing capacity for height ranged from —12.4 to 14.4 per cent, the average being —6.7 per cent for the girls and —7.6 per cent for the boys. After treatment, varying from 88 to 513 days, the average breathing capacity was —.4 per cent for the girls and —3.0 per cent for the boys. Stewart wrote:

> "The moderate reduction in vital capacity present at the time of the admission to the Lymanhurst school was probably due in part to their general under-nutrition and probably to the presence of enlargement of tracheobronchial lymph nodes. Of the two factors undernutrition was considered the more important. The beneficial results of the care given these children at Lymanhurst is reflected by the improvement of the vital capacity of the lungs as well as by the improvement in nutrition." (112, p. 283)

In 1929, Friedman and Howes (45) measured the breathing capacity of 200 children seven to twelve years old in the Prendergast Preventorium. All had been exposed to an open case of tuberculosis and showed positive Pirquet tests. Using the Stewart and Sheets norms, they found that "the vital capacity of each of the children at this institution was practically normal." (p. 363) Of nine children who were 15 per cent to 42 per cent below normal, they found that seven had heart disease and two had marked scolioses.

> "We seem justified in concluding as a result of this study that the estimation of vital capacity, in the quiescent case of

> hilum tuberculosis . . . is of no value in diagnosis . . . this conclusion does not necessarily apply to the diagnosis of active hilum tuberculosis showing clinical signs and symptoms." (p. 363)

Dreyer and Hanson (38) from their study (previously described) concluded:

> "It is perhaps worth recording that changes in vital capacity appear to offer an unusually trustworthy index of any improvement or deterioration taking place in the pulmonary lesions of patients with tuberculosis of the lungs. It also appears from the study of a tolerably large number of such cases that determinations of the vital capacity and its changes may be of value in prognosis, and help the physician to decide, for example, which patients are likely to benefit by further sanatorium treatment and which are not." (38, p. 20)

Tracheobronchial Adenopathy.—Wilson, Edwards, and Liss (128) studied the breathing capacity records of children five to twelve years of age with diagnosed tracheobronchial adenopathy, comparing them with their 1921 standards. They found a reduction of 15 to 42 per cent in breathing capacity for this group. In a group of supposedly "normal" subjects of the same age, "diminished vital capacity and roentgenological evidence of tracheobronchial adenopathy were found in 16 per cent of apparently normal white subjects, and 84 per cent of apparently normal colored subjects." (p. 59) They concluded that "vital capacity is an aid in the diagnosis of tracheobronchial adenopathy." (p. 59)

Trunk Deformities.—Flagstad and Kollman (43) followed the changes in breathing capacity of one hundred subjects, five to forty-one years old, during treatment for scoliosis. From these repeated readings and roentgenograms they concluded: "Vital capacity bears a definite relationship to the location, degree of curvature and rotation." (p. 730) "In mild and moderate cases, regardless of muscle power, vital capacity is within normal limits. In severe cases the vital capacity varies from 53 to 65 per cent." (p. 732-73)

Hansson (55) in 1939 reported the results of repeated breathing capacity measurements of 564 patients with scoliosis and 441 with antero-posterior curves at the Hospital for the Ruptured and Crippled, New York City. Using Edwards and Wilson's standards, he found that 95.2 per cent of the scoliosis cases were below normal (i.e., below 99 per cent in breathing capacity) and 26.2 per cent were below 50 per cent. Of those suffering from paralytic

scoliosis, 47.7 per cent had breathing capacities below 50 per cent of the standards. He wrote:

> "I have followed some of these children over long periods, i.e., three to six years, and I have always been impressed by the parallel improvement in appearance as shown by the photographs and the gradually increasing vital capacity. This has been accomplished by a combination of rest, proper nutrition, and therapeutic exercises. . . . Finally, we must consider the specific corrective exercises which should be concentrated on the diaphragm and the thoracic cage. Plaster jackets and various braces for support are detrimental to the general health of a child as determined by the vital capacity and should only be used when definitely indicated as a necessity for structural support. . . . I believe that in vital capacity determination we have an objective record of the child's health as far as heart and lungs are concerned." (p. 75-76)

Heart Disease.—Wilson and Edwards (126) compared the breathing capacity of a number of children with diagnosed heart ailments with their 1921 standards. They reported that eighty-eight children with heart disease and normal exercise tolerance had an average breathing capacity 2 per cent below the norm; thirty-six children with heart disease and diminished exercise tolerance averaged 26 per cent below the norm; while thirty-five potential cardiacs with normal exercise tolerance showed average breathing capacity. They concluded: "Vital capacity measurements show a close relation to the heart functional capacity as gauged by the exercise tolerance." (p. 454) Pratt (97) agreed with these findings in his report of a series of case studies of breathing capacity measurements taken repeatedly for several years on a number of cardiacs. He stated that his records showed "the value of long continued observations of the vital capacity repeated over a long period of time in measuring the increase or decrease of cardiac power. They will be found to be a distinct aid in the treatment and prognosis of heart disease." (p. 832)

Anemia.—Parsons and Wright (92) reported a clinical study of five children, four to seven and one-half years old, with diagnosed anemias. They found that all showed markedly lower breathing capacities than did a control group of ten normal children when compared with Wilson and Edwards' standards. After treatment, three increased their breathing capacity readings. They wrote:

> "These measurements of vital capacity are not altogether

> satisfactory, for there is undoubtedly a knack of using the spirometer to the fullest advantage, and it is almost impossible to judge at what point the child acquires this facility." (p. 28)

Hookworm.—Roberts (101) studied the breathing capacities of 1,000 Alabama children, six to eighteen years old, all of whom were infected with hookworm in varying degrees. Comparing their breathing capacities with Stewart's norms for height, for weight, and for sitting height, he concluded: "Hookworm infection does not materially decrease the vital capacity of the child population between six and eighteen years of age when this population is considered as a whole." (p. 780)

Stiles and Graves (114) confirmed this finding in a rather curious study in which they analyzed the breathing capacity of 1,618 children, six to seventeen years old. They classified the children in sanitation groups as: P, having privy; S, having sewer connection but no privy; and U, sanitary provisions unknown. They found no significant differences in breathing capacity between the sanitation groups, although there was some tendency for the *S* group to exceed the *P* group. When these children were classified as to hookworm infection, no apparent difference in breathing capacity was found between the infected and the noninfected.

Pneumonia.—No pneumonia studies have been reported on children. That made by Arnett and Kornblum (10) for adults, using daily breathing capacity records of twelve pneumonia cases, will serve to illustrate the findings in this field. The daily records showed a sharp decrease at the crisis with a rapid rise following in cases which recovered. Certain complications of the disease were found in those cases which failed to show a rise following the crisis. They believed that breathing capacity readings were an adjunct to the usual clinical pulse, temperature, and respiratory record aids in visualizing the course of the disease. They wrote: "An extremely low vital capacity may assist in differentiating pneumonia from diseases which do not lead to such a marked reduction." (p. 274)

Miscellaneous Diseases.—Wilson and Edwards (127) prepared a chart of clinical conditions revealing a diminished breathing capacity in children as follows:

Clinical Condition	Per cent Reduction
Tracheobronchial adenopathy	20 to 30
Acute bronchitis	10 to 20
Bronchial asthma (between attacks)	0 to 30
Emphysema	10 to 15
Pleurisy with effusion	30 to 40
Lobar pneumonia	40 to 50
Pulmonary tuberculosis	30 to 50
Organic heart disease	
Normal exercise tolerance	0 to 3
Diminished exercise tolerance	20 to 35
Cardiac failure	35 to 80

For each condition, repeated breathing capacity measurements were found to vary with the course of the disease and to be of prognostic value.

Hinckley (60) studied the breathing capacity of students at the University of Minnesota, selecting groups of about 200 each whose breathing capacity was below 80 per cent, 80 to 89 per cent, 90 to 109 per cent, 110 to 119 per cent, and more than 120 per cent of the values obtained from West's surface area formula. He found no differences in blood pressure, pulse rate, posture, or incidence of positive and negative Mantoux tests. He analyzed the disease conditions found in the students and their family histories, and found pneumonia, influenza, and pleurisy reported most frequently by the low vital capacity groups, but the findings were not consistent. There was little difference in the occurrence of rheumatic fever, St. Vitus dance, and tuberculosis. He then selected one hundred students with diagnosed physical conditions and compared their breathing capacities with those of one hundred normal students.

Students	Average Breathing Capacity, Per cent
100 normal	98.7
2 active tuberculosis	90.0
16 arrested tuberculosis	90.9
69 organic heart defects	94.6
24 asthma	95.4
12 diaphragmatic pleurisy	88.3

He concluded that breathing capacity as a test had little diagnostic value.

Baldwin (13) noted that growth in breathing capacity was materially affected by the inception of and recovery from disease.

Myers (90), who compiled an extensive review of the literature prior to 1929, summarized the findings relative to disease by saying:

> "Conditions of present clinical significance which reduce the vital capacity are: cardiac disease, hyperthyroidism, emphysema, asthma, pleurisy, pneumothorax, pulmonary abscess, new growths, pneumonia, and pulmonary tuberculosis. Vital capacity readings therefore render considerable aid in the diagnosis, the guidance of treatment and the prognosis in these conditions. At present it is most valuable in cardiac disease, pneumonia, and pulmonary tuberculosis." (p. 69)

Conditions of No Clinical Significance which May Reduce Breathing Capacity.—Myers (90) has listed "old pleural adhesions, deformities of the thorax and ossification of the costal cartilages" (p. 69) as conditions which may decrease the breathing capacity. "In addition to these, malingering, lack of co-operation, and will power must be considered. There is a small group of persons with low vital capacities in whom no cause has been found." (p. 69) To this list Moersch (88) has added: posture, flexibility of the thorax, intra-abdominal pressure, retraction and displacement of lung tissue, diverticula of the esophagus, and certain psychic influences.

Summaries.—During the last five years two summaries of the present status of breathing capacity as a clinical instrument have been prepared by medical men. In 1937 Arnett and DeOrsay (9) wrote:

> "It would be . . . impossible to draw an arbitrary line and say beyond this line the variability is so great that the test is of no diagnostic value for any disease. . . . It would be possible if we knew the variations to be expected in any particular disease, to say for this disease the test might be helpful in students whose variations would not exceed such and such a figure. . . . The diagnostic value of any given vital capacity will depend chiefly upon: (a) whether the vital capacity loss is great in comparison with previously observed variation; and (b) whether the magnitude of the vital capacity loss is commensurate with what is expected in the particular disease under consideration." (p. 687)

Thomas (116) in 1935 reviewed the clinical literature and drew the following conclusions:

> "1. Vital capacity is a measure of the impairment of either respiratory or circulatory function, although from studies of

the vital capacity alone, little insight into the different causes may be gained. . . .

"2. Measurements . . . [of x-ray films of the thorax] . . . conform more closely with actual pulmonary capacity than do any other body measurement.

"3. Vital capacity when reduced by different types of lesions may owe its reduction to alterations in the various subdivisions of total lung volume and should therefore be studied in conjunction with residual air and total capacity." (p. 1686-1687)

Myers (90) was so enthusiastic about the vital capacity test that he suggested that spirometers should be installed in public places so that persons would "become familiar with their actual vital lung capacities" and learn to seek advice if their "actual lung capacity decreased more than 10 or 15 per cent." (p. 89) After reviewing over 300 studies of breathing capacity he summarized the uses and limitations of the measure as follows:

"Like every other test and phase of examinations, as made today, the vital capacity test is not infallible. . . . Individual variation offers one of its greatest limitations. One who may have ordinarily a vital capacity of 125 per cent of theoretical normal may develop a disease which materially reduces his vital capacity, and yet the readings may be well within the generally accepted normal limits. This difficulty may be overcome if the vital capacity of individuals while in a normal state of health is recorded. In the differential diagnosis of chest diseases the vital capacity test gives us very little aid. Probably the only help we receive from it is in differentiating pneumonia from certain other acute diseases. It also serves as excellent differential evidence between pneumonia and acute appendicitis. . . .

On the other hand its uses are many and very definite. It can tell us roughly, yet quickly, whether there is involvement of much clinical significance affecting the heart or lungs directly or indirectly. It aids in differentiating between pneumonia and certain other acute diseases of the respiratory tract. It gives valuable information regarding the severity of lesions, especially tuberculous lesions. . . . The test is a good index as to the effects of treatment of diseases of heart or lungs." (p. 71-72)

GRIP STRENGTH AND HEALTH

The literature on the relationship of strength to health deals mainly with batteries of strength tests designed to estimate the total strength of the body. Of these the strength index and its derivative, the physical fitness index, as defined by Rogers (103), have perhaps

received most attention. To review the literature dealing with this test or the modifications of it is beyond the scope of the present study for two reasons: (1) there has been little specific analysis of the grip strength test per se, and (2) the battery is not adapted for use with preschool children. However, the principle underlying the use of strength tests as a measure of physical condition or fitness may be applicable to the single test of grip strength in so far as grip strength may be considered a representative sampling of the strength of the body. This theory of the relationship of strength to health has been stated by Rogers (105) as follows:

> "The positive and very high relation of muscular strength to general health, physical fitness, or 'capacity for activity' can hardly be questioned. With no strength there can be no physical activity; moreover, when muscular strength is low, all other life functions are handicapped. . . . The relation of the effective condition of voluntary muscle tissue to other organic conditions is just beginning to be recognized; but experiments are multiplying which reveal, beyond peradventure, the truth of the following rule: Practically every change in the condition or function of the vital organs has a corresponding change in the condition or functioning of voluntary muscles." (p. 34-44)

A somewhat more conservative point of view regarding the value of strength tests as a measure of health status has been expressed by McCloy (80):

> "Rogers first proposed that this P.F.I. (Physical Fitness Index) might be used as a measurement of health, and subsequent studies have tended to be in accord with this suggestion. Data presented by Chamberlain and Smiley (26) showed that the P.F.I. and medical examinations correlated about .60, while data presented by Hernlund (59) and reanalyzed by the present author gave approximately the same figure. Anderson (6) working with girls and women and using a carefully prepared semi-objective rating scale upon which the girls indicated how they felt most of the time, found a much lower figure, .207. This low correlation was probably as much attributable to lack of experience upon the part of the girls in taking the strength tests, as to the lack of validity of the criterion ratings.
>
> "Strength tests in the form of the Physical Fitness Index contribute much to the estimation of present health. They are not infallible and leave much to be desired, but they correlate highly with physicians' estimates of health status, and it must be remembered that physicians' estimates of health have in themselves only a reliability of about .6. (Franzen (44)).

> The Physical Fitness Index as a measure of health is a very desirable supplement to the medical examination. Where a low P.F.I. is found, the individual should be carefully examined by a competent physician before being assigned to strenuous physical activities.
>
> "Since strength is the most important element in motor performance, it is felt that strength relative to age and weight, expressed in the form of a Physical Fitness Index, is an excellent measure of an individual's general ability to work. An individual whose strength is less than normal for his age and weight, whether this is due to over-weight or insufficient muscle, fatigues very easily. He is usually tired by midafternoon and inefficient by evening. His chronic fatigue results in fatigue poisoning, with higher susceptibility to common infections. We believe that strength tests should be used as a routine measure of general physical status of individuals, both in youth and as adults. It might be added that these tests are also excellent motivators for improvement of physical condition." (p. 26-27)

Studies dealing specifically with the relationship of grip strength to measures of health or physical condition are few in number. Gates (48) correlated the grip strength of junior primary and fourth grade pupils (previously described) with ratings of "physical vigor" made by five teachers. The average correlation was .31. When nutritional status (weight from the Baldwin-Wood tables minus actual weight) was added, the multiple correlations averaged .45. Grip, nutrition, and weight gave .52; grip, nutrition, weight, and lung capacity, .52; grip, nutrition, weight, lung capacity, and chest girth, .54; grip, nutrition, weight, lung capacity, chest girth, and height, .61; and grip, nutrition, weight, lung capacity, chest girth, height, and ossification ratio, .61. He concluded:

> "The degree of ossification of the carpal bones, measures of nutrition, weight, height, grip, or any other single physical trait is mildly indicative of the general physical efficiency status, but when all of these are properly combined, they yield a significant measure." (p. 341)

MacDonald (83) classified 1,100 college women as to disease history. He found no significant relationship between strength of grip and the number of diseases reported by the subjects.

MacCurdy (81) classified 103 sixteen-year-old boys as athletes or non-athletes. He obtained a biserial correlation of .44 between grip strength and athleticism. In a similar study Shaffer (107) classified ninety freshman and seventy-five senior boys into those who were team athletes, individual athletes, and non-athletes. He

found statistically significant differences in grip strength for the three groups in the order named. When he repeated the study with high school senior girls, he found the same pattern for mean strength, but the differences were not statistically significant. He used actual grip strength and made no attempt to take differences in size into account.

Anderson (6) found a correlation of .17 between grip strength and an "endurance ratio" which she devised for 300 girls in grades ten and eleven. Wissler (129) reported a correlation of —.34 between grip strength and fatigue as measured by Cattell's ergometer for 140 college freshmen.

It will be seen from this brief review that as yet no very conclusive evidence has been adduced regarding the existence of a positive relationship between grip strength and physical condition.

QUOTIENTS FOR BREATHING CAPACITY AND GRIP STRENGTH IN RELATION TO THE HEALTH OF PRESCHOOL CHILDREN DURING THE SCHOOL YEAR

All the children in the present study were sufficiently healthy to be in attendance at preschool and to pass rigorous daily inspection by a trained preschool nurse. Within the group, however, as within any group, different individuals appeared to manifest varying degrees of physical well being. Some appeared to be in excellent condition and were almost never absent from preschool. Others were subject to frequent colds and minor ailments and were absent as much as one-third of the time. Two children had asthma, three had chronic sinus infections, one a moderate degree of scoliosis, and one suffered from an allergic condition which resulted in frequent nasal discharge.

It was the purpose of the present analysis to determine whether or not the breathing capacity quotient and/or the grip quotient served to differentiate degrees of health within the fairly narrow range represented in these subjects.

To the nonmedical person working with young children in a preschool situation the concept of health must be a functional one. It must deal primarily with the question: How adequately is this child able to meet the demands made upon him by the preschool environment? Is he well enough to attend preschool with a fair degree of regularity and participate in the preschool activities without showing undue fatigue, or is his condition such that he becomes easily overfatigued and is highly susceptible to colds and other

minor infections? It was with such considerations as these in mind that the criteria of health used in the present study were selected. It is recognized that each of them is only indicative of a certain aspect of the child's total health picture, and that all possess varying degrees of unreliability.

The first criterion selected was that of preschool attendance. In the preschool laboratories of the Iowa Child Welfare Research Station careful records are kept of the attendance of each child. Every absence is investigated and the reason for it recorded by the preschool nurse. Four uses were made of these records.

1. Total amount of time each child was absent for illness during the school year: For those children tested in the spring of 1939, the attendance records of the school year 1938 to 1939 were examined. The number of days each child was absent for illness was determined. This number was then reduced to the per cent of total days of possible attendance for each child, since the number of days of possible attendance was not the same for all groups. For those children tested in the fall of 1939, the records for the school year 1939 to 1940 were used. The number of days each child was absent for illness prior to April 29, 1940 was determined. Since the number of days of possible attendance for all groups was the same, the number of days absent for illness was not changed into a percentage score.

2. The number of absences for each child: This measure was the number of times the child was ill enough to be absent, regardless of the number of days of absence the illnesses entailed.

3. Number of absences greater than one day: This measure is the same as (2) except that illnesses so slight as to necessitate only one day of absence from school were omitted.

4. Number of absences greater than two days in length: This is the same as (2) and (3), except that minor colds and fatigue so slight as to keep the child home for only two days were omitted.

The second, third, and fourth absence measures were used in an attempt to get some indication of the frequency and duration of illness. A child who was frequently absent for a day or two because of a cold or certain cold symptoms would have a high score on the second measure, while he might have a low score on the fourth or first. A child who had only one serious illness which might keep him home for several weeks would have a high score on the first measure and low scores on the second, third, and fourth.

It is believed that these four measures represent somewhat different aspects of the whole absence picture.

The second criterion of physical fitness employed was health judgments. Each child was rated as to degree of health by the preschool nurse who examined him each day. These ratings were described in Section I, Chapter II.

The third health criterion used was fatigue judgments. A rating of the fatigability of the child was secured from each of the preschool teachers who supervised his rest and play. These ratings were also described in Section I, Chapter II.

Product-moment correlations of these criteria were computed, using Sheppard's correction for coarseness of grouping for the ratings. These are shown in the following tabulation:

Health Ratings With	Correlation
Fatigue ratings (First, Second, and Third Groups)	.44
Energy expenditure ratings (Jr. Primary)	.26

Amount of Time Absent for Illness With	Fall	Spring
Health ratings	.26	.26
Fatigue ratings	.37	.15
Energy expenditure ratings	.10	.30
Number of absences	.52	.72
Number of absences longer than one day	.68	.76
Number of absences longer than two days	.78	.81
Number of Absences with		
Health ratings	—.04	.16
Fatigue ratings	.00	.27
Energy expenditure ratings	.03	.35

The low intercorrelations between the ratings and the absence records may indicate that each represents a different aspect of the total health picture, or they may be simply a function of the unreliability of the measures. Probably they are a result of both factors. At least they indicate that the teachers and nurses were not greatly influenced by the absence records of the children in making their estimates of health and fatigue.

In analyzing these estimates of health status with reference to the breathing capacity quotient and the grip quotient the results of the spring and the fall testings were treated separately. The children in the preschool First and Second Groups and Junior Primary who were tested in the spring of 1939 had been in attendance during the school year 1938 to 1939. In the following pages this group is referred to as the *spring data.* For this group the

breathing capacity and grip quotients have retroactive implications. That is, if any health relationships exist, they are mainly an expression of what has happened to the child during the preschool year just past.

The children in First, Second, and Third Groups and Junior Primary who were tested in the fall of 1939 were in attendance during the preschool year 1939 to 1940. In the following pages this group is referred to as the *fall data.* For this group the breathing capacity and grip quotients carry predictive implications. That is, if any relationships exist between the quotients and the health criteria, it may be assumed that the quotient scores are indicative of what the health status was to be during the current preschool year.

The general procedure in the analysis is described for the spring data for breathing capacity quotient. The same procedure was followed for the fall data, except that the children from First Group were included. The procedure for analyzing the grip quotient data is identical with that described for the breathing capacity quotient.

Separate distributions of the breathing capacity quotients were made for the children in Second Group, Third Group, and Junior Primary. Each distribution was divided into three parts: the highest third, the middle third, and the lowest third.[13] For the children in each third of each group the means were computed for the health ratings, the fatigue ratings,[14] and each of the four absence scores. These means were arranged in six two-way tables and the method of analysis of variance used to determine whether or not there were any significant differences among the health scores for the three quotient divisions. For each table the estimate of the variance of *quotient groups,* for *classes* (preschool groups), for interaction of *quotient groups by classes,* and for *within groups* (or children) was computed.

[13] It was not possible to combine all of the children into one distribution since: (1) the amount of absence from preschool decreases with increasing age; and (2) the health and fatigue ratings were made as of each specific group (i.e., a child was designated as above average, average, or below average with reference only to the preschool group to which he belonged.) In no instance, however, do the division points for the quotients differ by more than two quotient points from group to group.

[14] The fatigue ratings for First Group, Second Group, and Third Group and the energy expenditure ratings for Junior Primary have been combined in this presentation. This may not seem entirely defensible since they were made on slightly different bases, but separate analyses of the ratings in relation to the quotients gave approximately the same results.

The tables of means for each health criterion are shown below. The pertinent variance statistics are given only for those for which the differences are statistically significant.

Spring Data: Breathing Capacity Quotient	Number	High	Medium	Low	All
Nurses' Health Ratings					
Second Group	18	3.17	3.60	3.17	3.31
Third Group	24	2.88	3.44	3.31	3.21
Junior Primary	36	3.09	2.45	3.25	2.85
Total	78	2.75	2.85	3.21	2.94
Fatigue Ratings					
Second Group	18	2.50	3.00	3.50	3.00
Third Group	24	2.88	3.44	3.31	3.21
Junior Primary	36	3.13	2.77	3.05	2.90
Total	78	2.90	3.03	3.11	3.02
Number of Absences for Illness					
Second Group	18	6.83	6.00	6.83	6.56
Third Group	24	6.50	6.63	5.38	6.17
Junior Primary	36	2.50	3.91	3.17	3.19
Total	78	4.73	5.23	4.69	4.88
Number of Absences Greater Than One Day					
Second Group	18	5.17	3.20	5.83	4.73
Third Group	24	5.63	5.25	3.88	4.92
Junior Primary	36	2.50	3.91	3.17	3.19
Total	78	4.08	4.15	4.00	4.08
Number of Absences Greater Than Two Days					
Second Group	18	5.00	2.40	4.33	3.91
Third Group	24	4.50	4.38	3.25	3.73
Junior Primary	36	1.58	2.73	2.42	2.24
Total	78	3.27	3.16	3.12	3.18
Per cent of Time Absent for Illness					
Second Group	18	21.17	11.20	19.17	17.18
Third Group	24	20.88	19.50	14.75	18.38
Junior Primary	36	7.58	13.36	13.17	11.37
Total	78	14.81	14.75	15.04	14.87

No significant differences in the means of the health criteria were found for the breathing capacity quotient groupings of the spring data. From this it is evident that breathing capacity quotients obtained in the spring bear little relationship to the child's absence record for the previous seven months or to the ratings of fatigue or health status based on observations made during that time.

Fall Data: Breathing Capacity Quotients

	Number	High	Medium	Low	All
Nurses' Health Ratings					
First Group	9	2.33	2.67	3.00	2.67
Second Group	21	2.57	2.83	2.86	2.75
Third Group	24	2.38	3.00	3.50	2.96
Junior Primary	36	2.92	2.56	3.17	2.83
Total	90	2.63	2.75	3.07	2.82
Fatigue Ratings					
First Group	9	3.17	2.83	2.83	2.94
Second Group	21	2.57	3.25	2.86	2.89
Third Group	24	2.30	2.57	3.56	2.88
Junior Primary	36	3.08	3.08	3.00	3.05
Total	90	2.82	2.96	3.10	2.96
Number of Absences for Illness					
First Group	9	8.00	7.67	6.67	7.44
Second Group	18	6.83	6.17	7.00	6.67
Third Group	21	5.14	6.63	5.71	5.83
Junior Primary	33	6.50	6.55	5.36	6.14
Total	81	6.39	6.61	5.96	6.32
Number of Absences for Illness Greater Than One Day					
First Group	9	5.50	5.33	5.00	5.28
Second Group	18	4.67	5.33	4.50	4.83
Third Group	21	3.71	5.25	4.14	4.37
Junior Primary	33	3.80	4.73	4.45	4.33
Total	81	4.16	5.06	4.44	4.56
Absences for Illness Greater Than Two Days					
First Group	9	3.50	5.00	3.33	3.94
Second Group	18	3.50	3.50	3.50	3.50
Third Group	21	2.86	3.75	2.86	3.15
Junior Primary	33	2.10	3.73	3.36	3.06
Total	81	2.76	3.82	3.26	3.28
Number of Days Absent for Illness					
First Group	9	25.00	30.67	34.33	30.00
Second Group	18	26.50	27.50	28.00	27.33
Third Group	21	16.43	26.75	25.14	22.77
Junior Primary	33	17.70	24.91	22.36	21.66
Total	81	20.14	26.60	25.67	24.14

For none of the health criteria used were there any significant differences among the means of the breathing capacity quotient groupings of the fall data. It may be noted that there is a tendency for the high breathing capacity quotient group to have a better record than either the medium or low groups. These differences, however, are not marked, and it would seem to be straining the findings to attempt to attach any practical significance to them.

Spring Data: Grip Quotients

	Number	High	Medium	Low	All
Nurses' Health Ratings					
Second Group	9	3.67	3.00	3.33	3.33
Third Group	24	2.50	3.06	2.81	2.83
Junior Primary	36	2.42	2.82	3.33	2.86
Total	69	2.61	2.93	3.15	2.90
Fatigue Ratings					
Second Group	9	3.67	3.00	4.00	3.56
Third Group	24	3.19	3.13	3.31	3.21
Junior Primary	36	2.75	3.14	3.08	2.99
Total	69	3.02	3.11	3.28	3.14
Number of Absences for Illness					
Second Group	9	5.67	8.33	5.33	6.44
Third Group	24	6.13	7.00	5.38	6.17
Junior Primary	36	4.67	7.09	5.67	5.81
Total	69	5.30	7.22	5.52	6.02
Absences for Illness Greater Than One Day					
Second Group	9	3.67	7.33	4.00	5.00
Third Group	24	4.88	6.25	3.63	4.92
Junior Primary	36	2.17	3.91	3.50	3.19
Total	69	3.30	5.17	3.61	4.03
Absences for Illness Greater Than Two Days					
Second Group	9	3.67	6.33	3.00	4.33
Third Group	24	4.13	5.25	2.75	4.04
Junior Primary	36	1.25	3.00	2.67	2.31
Total	69	2.57	4.32	2.74	3.17
Per cent of Time Absent for Illness					
Second Group	9	14.00	25.33	15.33	18.22
Third Group	24	15.75	22.13	17.25	18.38
Junior Primary	36	6.33	14.36	13.50	11.40
Total	69	10.61	18.49	15.04	14.72

	d.f.	Variance
GQ* Groups	2	359.4047
Classes	2	414.0345
GQ x Classes	4	38.8801
Within Groups	60	86.7854

GQ x Classes /Within Groups	F	.45	Not significant
GQ Groups/ GQ x Classes	F	9.24	Significant at 5 per cent level
GQ Groups/ Within Groups	F	4.14	Significant at 5 per cent level

* Grip Quotients

High GQ* — Medium GQ	—7.89	Significant at 2 per cent level ("t" test)
High GQ — Low GQ	—4.43	Significant at 7 to 8 per cent level ("t" test)
Medium GQ — Low GQ	+3.45	Not significant

* Grip Quotients

The differences in the means of the health criteria for the grip quotient groupings in the spring data are significant only for the per cent of time absent for illness during the preceding months. The high grip quotient group tends to be absent less than the medium and low grip quotient groups, but it does not follow that the low group is absent more than the medium grip quotient group. For the fatigue ratings and health ratings there is a tendency for the high grip quotient group to exceed the medium grip quotient group, which in turn exceeds the low grip quotient group. These differences, however, are too slight to be significant either statistically or practically.

	Fall Data: Grip Quotients			
	Number	High	Medium	Low	All
		Nurses' Health Ratings			
First Group	9	2.67	2.00	3.33	2.67
Second Group	21	2.57	3.00	2.57	2.71
Third Group	24	3.00	2.56	3.25	2.94
Junior Primary	36	2.92	2.73	2.75	2.72
Total	90	2.83	2.58	2.90	2.77
		Fatigue Ratings			
First Group	9	2.67	3.00	3.17	2.94
Second Group	21	3.00	2.86	2.71	2.86
Third Group	24	2.50	2.57	3.57	2.88
Junior Primary	36	3.17	3.17	2.83	3.06
Total	90	2.90	2.92	3.03	2.95
		Number of Absences for Illness			
First Group	9	6.67	7.33	8.00	7.33
Second Group	18	7.33	6.17	6.50	6.67
Third Group	21	5.50	5.86	6.29	5.88
Junior Primary	33	4.91	7.00	7.00	6.30
Total	81	5.79	6.56	6.81	6.39
		Absences for Illness Greater Than One Day			
First Group	9	4.33	6.00	6.00	5.44
Second Group	18	5.50	4.50	4.67	4.89
Third Group	21	4.00	4.57	4.71	4.43
Junior Primary	33	3.45	4.30	5.27	4.34
Total	81	4.15	4.60	5.07	4.61

Fall Data: Grip Quotients

	Number	High	Medium	Low	All
	Absences for Illness Greater Than Two Days				
First Group	9	3.33	5.00	4.67	4.33
Second Group	18	3.83	3.00	3.50	3.44
Third Group	21	2.61	3.43	3.43	3.20
Junior Primary	33	2.00	3.10	4.18	3.09
Total	81	2.75	3.37	3.89	3.34
	Number of Days Absent for Illness				
First Group	9	24.33	40.67	37.67	34.22
Second Group	18	24.50	28.00	27.83	26.78
Third Group	21	19.00	23.71	26.71	23.14
Junior Primary	33	15.19	21.70	30.45	22.45
Total	81	19.26	25.73	29.70	24.90

	d.f.	Variance
GQ* Groups	2	750.3841
Classes	3	369.7937
GQ x Classes	6	84.1621
Within Groups	69	161.8564

* Grip Quotient

GQ x Classes/ Within Groups	F		Not significant
GQ Groups/ GQ x Classes	F	8.96	Significant between 5 and 1 per cent levels
GQ Groups/ Within Groups	F	4.64	Significant between 5 and 1 per cent levels (4.92 at 1 per cent)
High GQ — Low GQ		—10.44	Significant at 1 per cent level ("t" test)
High GQ — Medium GQ		— 6.47	Significant at 5 to 10 per cent level ("t" test)
Medium GQ — Low GQ		— 3.97	Not significant

The fall data on the number of days absent for illness shows differences in the means for the high, medium, and low grip quotient groups which are statistically significant at about the 2 per cent level. Children in the upper one-third of the grip quotient distributions were absent an average of 19.3 days, those in the middle third 25.7 days, and those in the lower third 29.7 days. In other words, the children having high grip quotients in the fall of the school year were absent during the following seven months only about 65 per cent as much as those having low grip quotients. For the other absence criteria and the fatigue ratings there is a tendency for high grip quotient groups to have better records than medium and low grip quotient groups, but the differences are not marked. For the health ratings, no differences were found.

In summarizing these twenty-four analyses, it may be concluded

that breathing capacity quotients, whether obtained in the spring or in the fall, show no statistically significant relationship to absence records, fatigue ratings, or health ratings. The grip quotient, obtained either in the fall or in the spring, serves to differentiate between the children who are absent more than the mean amount for their preschool group and those who are absent less than the mean amount for their group. The distinction between the high grip quotient group and the medium and low groups is reasonably marked, but little difference is found between the medium grip quotient and low grip quotient groups. For the other absence criteria and the fatigue ratings, there is slight evidence of a relationship with the grip quotients obtained in the fall. For the health ratings and grip quotients no evidence of any relationship is found.

It has been shown that the grip quotient serves to differentiate those groups of children who are absent a great deal from those who are absent a smaller proportion of time during the school year. It remains to be seen whether this relationship will hold for individual children to the extent that it may be used for predictive purposes.

To obtain an index of the amount of relationship, a correlational approach was used. The grip quotients were plotted against the amount of absence in terms of deviations from the mean absence for each group. These were first plotted in a four category table divided according to above or below the mean grip quotient and above or below the mean absence for the group. For this four cell table, the tetrachoric correlation between grip quotient and amount of absence was —.42 for the fall data and —.51 for the spring data.

The per cent of children in each grip quotient category who were absent more than or less than the average amount of time for their preschool group is shown below:

Mean Grip Quotient	Absent less than the average amount of time	Absent more than the average amount of time
	Fall Data	
Above	71.7	28.3
Below	45.7	54.3
	Spring Data	
Above	74.2	25.8
Below	45.9	54.1

From these percentage figures it would seem that while a high

grip quotient is a reasonably good indication that a child will not have an excessive amount of absence during the school year, it cannot be said that a low grip quotient indicates that he will be absent frequently. One possible interpretation of this finding would be that while a high grip quotient is evidence that a child is as strong as his record indicates, a low grip quotient may be partially the result of inadequate motivation, malingering, or lack of interest.

The tetrachoric correlations show only the gross relationship of scores above or below the grip quotient mean to amount of absences greater or less than the mean amount for the group for either variable. They take into account the direction but not the size of deviations from the mean. The degree to which amount of deviation from the mean for grip quotient is related to amount of deviation from the mean for absences may be shown by product-moment correlations. For the spring data the product-moment correlation was —.21, and for the fall data —.22. These correlations are low, and indicate that a very high grip quotient is not necessarily evidence that a child will be absent very little, nor that a low grip quotient is necessarily accompanied by a great amount of absence. In view of the many possible causes of illness, it is not surprising that the coefficients are not high. The correlations while low indicate that a relationship between strength of grip and susceptibility to illness exists.

Case studies of a number of individuals produced supplementary evidence that the grip quotients and breathing capacity quotients were at least indicative of health status. The first approach was made in terms of the health criteria. Seven children were rated either 1 or 2 by both the nurse and the preschool teachers and were absent less than the mean amount of time for their group. Eight children were rated either 4 or 5 by both the nurse and the preschool teachers and were absent more than the mean amount of time for their group. The quotients of these children are shown in the following tabulation:

	Grip Quotient		Breathing Capacity Quotient	
	Above 100	Below 100	Above 100	Below 100
High in three health criteria (n=7)	5	2	6	1
Low in three health criteria (n=8)	1	7	3	5

For the high group, the mean grip quotient was 105.6 as compared with 90.8 for the low group. The difference of the means for

the two groups is greater than one standard deviation of the grip quotient distribution for all preschool children in the present study, which was 12.8. For the high group, the mean breathing capacity was 108.3, and for the low group 91.8. The difference between these means is also greater than the standard deviation of the breathing capacity quotient distribution (13.4) for all preschool children.

Seven children with diagnosed physical ailments were studied individually. Three of these had chronic sinus infections, two had mild cases of asthma, one an allergic condition which resulted in continual nasal discharge, and one a mild scoliosis. The breathing capacity quotients and grip quotients of these children are shown below.

Case 1 had a chronic sinus infection. His breathing capacity quotient was 93 and grip quotient 67.

Case 2 also had a chronic sinus infection. His breathing capacity quotient was 77, and grip quotient 86.

Case 3 had a chronic sinus infection resulting in constant colds which were affecting the hearing in both ears. His breathing capacity quotient was 80, and grip quotient 92. This child was under medical care. During the summer months, following tonsillectomy, his condition improved. In the fall his breathing capacity quotient was 96 and his grip quotient 112.

Case 4 had asthma. This child had been placed on a restricted activity program by his physician. His breathing capacity quotient was 113, grip quotient 95.

Case 5 also had asthma. His breathing capacity quotient was 84, and grip quotient 95.

Case 6 suffered from an allergic condition. Because of his poor condition and continual nasal discharge he was not permitted to play outdoors during the winter months. His breathing capacity quotient was 88, and grip quotient 74.

Case 7 had a moderate scoliosis. He was absent 46 per cent of the time during the school year 1938 to 1939. His breathing capacity quotient was 73, and grip quotient 89.

These findings are by no means conclusive, since an equal number of cases might be cited of children having equally low breathing capacity and grip quotients in whom no symptoms of clinical significance have been noted. However, they do show that this small group of children who were definitely below par in health were also below the average of the group in both strength and breathing capacity.

For the children in the present study who were four years of age or older the expected weight for build was determined by the

McCloy (78, 79) formula. Dividing the actual values by the expected values gave a percentage index of the amount of under or over weight. The children were grouped as to over and under weight and the mean grip quotient and mean breathing capacity quotient computed for each group. These are shown below, with the number of children falling in each classification.

Weight Index	Number	Grip Quotient	Breathing Capacity Quotient
95 and below	20	98.5	104.6
96 to 100	46	100.3	101.5
101 to 105	59	101.2	96.7
106 to 110	25	100.5	100.3
111 and above	6	92.5	99.5

For grip quotient, there is some indication that the children who are underweight (below 95 per cent) and overweight (111 per cent and above) are less strong than those in the normal weight range (96 to 110). However, the difference between the underweight and the normal weight groups is very small and not statistically significant. The difference between the normal weight group and the over weight group is larger, but since there are only six children who were overweight, this difference is not statistically significant.

For breathing capacity quotient, there is no significant difference between the various weight classifications.

The expected arm girths for the children four years of age and older were also determined by the McCloy (78, 79) formulae, and the per cent of over or under "muscle" computed. As McCloy has pointed out, over-muscle does not have the same significance as over weight. In so far as limb girth indicates muscular development, greater limb girth than average may not be considered undesirable.

For forearm girth, measured over the greatest bulge of the muscles of the forearm, the indices ranged from 95 to 112. No significant differences in grip quotient were found for the children having muscle indices from 95 to 99, 100 to 104, 105 to 109, and 110 and above.

One further indication of the relationship of grip quotient to physical condition was found in a comparison of the seasonal differences. For the sixty-eight children tested in the spring, the mean grip quotient was 96.6. For the thirty-seven children tested in the summer, 99.9, and for the eighty-one children tested in the fall,

102.9. The difference between the spring mean and the fall mean grip quotient is statistically significant at the 1 per cent level. For breathing capacity quotient the spring mean was 99.9, the summer mean 99.2, and the fall mean 101.9. These differences are not significant.

These trends are further illustrated by the quotients of the individual children who were tested in the spring and again in the fall. The mean gain in grip quotient for thirty-two children was 7.7 points, as compared with the spring-fall difference of 6.3 points for the cross-sectional data. Twenty-one children (66 per cent) gained more than five quotient points, while four (13 per cent) lost more than five points. The range was from —14 to +26 points, the 90th percentile being +20 points and the 10th percentile —7.

For breathing capacity quotients the mean gain from spring to fall was 3.0 points for the individuals tested both times. The corresponding gain in the cross-sectional data was 2.0 points. Thirteen children (41 per cent) gained more than five points, while nine (28 per cent) lost more than five points. The range was from —34 to +32 points, the 90th and 10th percentiles being +17 and —12 respectively.

A possible interpretation of the differences found in the grip quotient means may be that in the spring of the year the children are more tired as a result of the winter and its accompanying colds than they are in the fall of the year. During the summer months they are outdoors a great part of the time and they begin to recover from the effects of the winter. When they return to school in the fall they tend to be in better physical condition as a result of the sunshine and rest they have had during the summer months. This observation, of course, is conjectural, but it has been the experience of many school teachers that the children are in better condition at the beginning of the school year in the fall, and that they tend to become more tired as the year goes on.

This chapter has produced no conclusive evidence that the grip quotient is a measure of the health status of any individual child. However, the various analyses which have been presented have all served to indicate that some relationship does exist between physical condition and the grip quotient. That this relationship is not perfect is to be expected. To expect any single test administered during one week of the school year to serve as a perfect or near perfect indicator of the condition of the child over an extended period

of time is to expect the improbable. At the beginning of a school year no reasonably precise forecast may be made of the many influences to which a given child will be exposed during the following months. Such influences are not constant for all children. Diet, rest, contact with infectious diseases, clothing, unusual demands upon the strength of the child, and many other factors differ greatly from child to child, and each will have its effect on the child's health status. Under such conditions, the fact that a single functional test administered over a period of a few days shows any relationship at all to the child's health status over an extended period of time seems evidence that such a test is a measure of at least one factor which helps to determine the physical condition of any given child. In so far as the grip strength test is a measure of the muscular strength of the body, it may be concluded that physical strength is related to the child's resistance to influences which tend to undermine his health. Or conversely, it may be concluded that the child who has an abundance of physical strength has a better chance of making a successful adjustment to his physical environment. As has been stated by McCloy in the quotation given on page 166, the stronger person is probably less subject to fatigue, and consequently should have a greater resistance to infections and be better able to meet any unusual demands which may be made upon him.

On the basis of the findings of the present study it seems justifiable to suggest that any child whose grip quotient is low (providing, of course, that the examiner is satisfied that the low quotient is not due to malingering, lack of interest, or poor motivation) at the beginning of the school year should be considered as possibly less able than the child with a high grip quotient to meet the physical demands which may be placed upon him. He may need more rest, or more outdoor activity, or some change in his diet. It is not suggested that a program of systematic exercise should be set up to develop the strength of any one muscle group, since greater grip strength per se may not be the fundamental requirement. Grip strength should probably be considered as being only symptomatic of a generally low physical condition which may result from any of a number of causes.

For the use of the breathing capacity quotient the case is less clear. There is little indication in the present study that it repre-

sents a valid measure of the health condition of the child over an extended period.

The findings of the present study seem to justify the suggestion that grip strength as a functional test for preschool children merits further investigation. If it could be administered routinely to many preschool children not only at the beginning and end of the school year, but at several times during the school year, and the changes in the quotient related to the child's physical condition during that time, the validity of the findings of the present study could be determined with a much higher degree of precision than has been possible with the data now available. If further experimentation demonstrates the usefulness of the test as a symptomatic measure of the child's health status, it would prove a useful addition to present preschool procedure.

CHAPTER XVI

THE RELATION OF DAILY VARIATIONS IN BREATHING CAPACITY AND GRIP STRENGTH TO THE OCCURRENCE OF COLDS

In the preceding chapter it was noted that health as measured over the entire school year showed some slight relationship to grip strength as measured at the beginning or end of the school year. No relationship with breathing capacity was found. A second aspect of possible health service of these two tests lies in the sensitivity with which they register daily changes in physical well-being. It is not unlikely that the onset or immediate effects of certain illnesses may be reflected in the test scores even though the cumulative effects of illness and recovery over the period of the preschool year fail to yield any marked relationship.

Three studies which might be considered as indicative of such a relationship are found in the literature. Arnett and Kornblum (10), in the study previously described, found daily measurements of breathing capacity to be an adjunct to other clinical measures in visualizing the course of pneumonia. Arnett (8) obtained a series of daily readings of breathing capacity for cases of pneumonia, spontaneous pneumothorax, and cardiac decompensation. He found that breathing capacity tended to decrease when body temperature rose, and to rise again when the temperature returned to normal.

Rogers (105) reported: "A recent study indicates that grip strength alone responds remarkably well to changes in general physical condition." (p. 44) He tested the grip strength of one subject forty years of age daily for a period of six months. From June 19 to July 22, during a period of heavy manual labor the subject's grip strength rose from 160 to 182 pounds. The following week, preceding an attack of "la grippe" it fell to 140 pounds, and remained at 140 to 144 pounds during the course of the illness. On recovery, the grip strength rose to 170 pounds and remained there for the next two weeks.

On July 22, the subject played nine holes of golf and attended a barn dance in the evening, with no marked decrease in grip strength. The following morning at 6 a.m. the grip strength had

fallen to 140 pounds, but rose to 160 pounds by evening. During an August vacation, grip strength rose to 182 pounds, and remained there during September, October, and November. In December after four days of severe nervous strain the grip strength dropped to 140, but rose to its normal height again when the strain was removed. Later in December an attack of severe laryngitis produced no drop in grip strength. The author attempted to explain this by suggesting that laryngitis was a local infection, the effects of which were chiefly discomfort rather than poor health.

It is not possible to generalize as to the relationship of grip strength and breathing capacity to daily changes in health status from such scanty evidence, but these studies do serve to suggest that the problem is one which might merit investigation.

For purposes of such an investigation twenty children in the Third Group were tested daily from November 15 to December 15, 1939, and twenty-two children daily from January 3 to February 23, 1940. These children were between four and five years of age.

In the preschool laboratories of the Iowa Child Welfare Research Station each child must be examined by the preschool nurse before he is permitted to enter his group for the day. These examinations are conducted in a separate building. Parents, older sisters, taxi drivers, or maids bring the children to school, take them in to the nurse, wait until the examination is completed and the child approved for the day, and then take them to the preschool building.

For the purposes of this experiment, the instruments were set up on a table in the nurse's office, slightly removed from the place at which she examined the children. After the nurse had examined each child she sent him over to the investigator for testing. This became a part of the routine examination, and after the first day or two the children accepted it as such, and came to be tested without instruction from the nurse.

It can be seen that the testing conditions were not ideal. The children did not arrive at evenly spaced intervals and there were sometimes from three to five children and the accompanying adults waiting at one time for the examination and the testing. Thus it was not possible to devote a great amount of time to any one child since this would have inconvenienced the waiting adults. A certain amount of confusion resulted from the presence of several children and adults, to which the children reacted in various ways. Some

enjoyed having an audience and liked to "show off" in front of them; others became shy and a little hesitant about performing the tests while adults and other children were watching. In spite of this confusion, however, the children and most of the adults continued to be interested in the results of the tests throughout the entire course of the experiment.

For the November-December testing the procedure was to allow each child two trials[15] for breathing capacity and two for grip strength. The highest score made in each case was recorded. Both trials for grip were with the right hand. (Since the results were to be used for comparative purposes only it seemed better to have all children use the same hand rather than to remember which was the "best" hand for each child.) The scores were plotted daily, separate graphs being made for each child. All absences were noted and the reasons for them determined and recorded by the nurse.

In a preliminary analysis of the November-December data the investigator found herself handicapped by having insufficient information about the child's health on Saturday and Sunday. To overcome this difficulty, during the January-February testing period all parents were contacted each Monday morning, either personally or by telephone, and asked for information as to the child's health over the week-end. The plan of going to the children's homes on Saturday morning to administer the tests was considered, but discarded for several reasons. First, the children's homes were rather widely scattered; secondly, this would have involved some inconvenience to the parents; and thirdly, because the conditions of such testing would not have been comparable with those in the school situation.

The November-December data, moreover, showed rather marked variations from day to day, and in an attempt to minimize some of these seemingly chance fluctuations a further factor was introduced into the January-February testing. The tests for the first two days were administered as in November and December. Then for each child the averages of these two days' scores were found and used as the criterion scores for the following day. The observer had these scores before her at the time of the testing and if any child fell markedly below his criterion scores for that day he was given another trial. New criterion scores were computed for each

[15] The time available for testing each child was not sufficient to permit the use of five trials for breathing capacity and six trials for grip strength as recommended earlier in this study.

day based on the averages of the two preceding days. If for any reason it seemed to the observer that a child was unquestionably not exerting maximum effort, the score was discarded and no record made for that day.

In analyzing these data for November-December and January-February a number of plans were considered. Those using deviations from some criterion scores seemed the most practical. Using deviations for each test from mean scores over the entire four months period was discarded, since some increase in score due to growth and possibly to practice over this length of time would tend to make such deviations positive at the end of the period, and negative at the beginning of the period. Fitting regression lines to the data for each child was considered, but such lines were too much influenced by the amount of illness and absence during the period, and by the time at which it occurred.

The method finally adopted was to compute the deviation of each day's scores from the averages of the scores made on the two preceding days. This gave a daily picture of the child's scores in relation to the trend of his scores at that time. The following analysis is in terms of such deviations, negative deviations being termed "drops" and positive deviations "rises." The November-December data and the January-February data are analyzed separately.

During the period of the investigation there were no serious illnesses in the group. Since the weather was severe during most of the time, and since influenza and colds were common in Iowa City during these winter months, there were many colds and a few cases reported as "flu." It seemed impossible to differentiate the different kinds and degrees of respiratory infection. For this reason the categorical term "colds" has been used to describe all illnesses characterized by some type of infection of the upper respiratory tract.

The first analysis was made in terms of the number and magnitude of "drops" for each of the tests. The scores made by each child (1) the day before he was reported to have a cold, (2) two days before he was reported to have a cold, and (3) the day he returned after having been ill, were tabulated separately. The heading "Non-cold" therefore refers to scores made more than two days before the incidence of a cold or more than one day after the child returned to school. The results of these tabulations are shown on pages 188-190. For the November-December data the colds re-

ported on Monday are tabulated separately as "week-end colds" since it is not known on which day of the week-end the cold first manifested itself.

The following tabulation and those similar to it may be read as follows: Of the 233 records from the November-December data which did not immediately precede or follow a cold ("noncold" records), eighty-six (or 37 per cent) showed decreases of .2 kg. or more from the criterion scores, sixty-one (or 25.2 per cent) showed decreases of .4 kg. or more, forty (or 17.2 per cent) showed decreases of .6 kg. or more, etc. For the twenty-nine records obtained on the day preceding a cold, fifteen (or 51.7 per cent) showed drops of .2 kg. or more. Of these fifteen cases, seven were colds which occurred during the week and eight were colds which began sometime during the week-end. Ten cases (or 34.5 per cent) showed drops of .4 kg. or more, five of these being colds which occurred during the week, and five being week-end colds.

	.2 kg. or More	.4 kg. or More	.6 kg. or More	.8 kg. or More	1.0 kg. or More*
Noncold (N=233)					
Number	86	61	40	26	18
Per cent	37.0	25.2	17.2	11.2	7.7
One day before cold					
Colds during week (N=14)	7	5	3	2	0
"Week-end colds" (N=15)	8	5	5	1	0
Total (N=29)	15	10	8	3	0
Per cent	51.7	34.5	27.6	10.3	0
Two days before cold					
Colds during week (N=11)	4	3	3	1	1
"Week-end colds" (N=15)	7	4	4	3	1
Total (N=26)	11	7	7	4	2
Per cent	42.3	26.9	26.9	15.4	7.7
One day after cold (N=22)					
Number	9	9	5	4	3
Per cent	40.9	40.9	22.7	18.2	13.6

* Since the average grip strength of these children was approximately 10 kg., a drop of .2 kg. equals 2 per cent, .4 kg. equals 4 per cent, etc.

It is evident from the preceding tabulation that a greater percentage of drops in grip strength occurred in connection with colds than for the noncold records. However, the differences in these percentages are statistically significant by the X^2 test only for drops of .6 kg. or more on the day preceding a cold.

Using the drops for one and two days before a cold from the November-December data a further comparison was made. These data were examined and the greater drop for either of the two days

selected. To compare these selected drops with drops occurring in the noncold data would result in a biased estimate since in each instance they represent only the lower of two days' scores. To make the noncold data comparable, a pairing procedure was adopted. Day one and day two were examined and the lowest score recorded, day three and day four were likewise paired and the lowest score taken, and so on for all the noncold data. The incidence and magnitude of drops in grip strength for these paired data are shown below.

	.2 kg. or More	.4 kg. or More	.6 kg. or More	.8 kg. or More	1.0 kg. or More
Noncold paired (N=157)					
Number	94	71	46	30	21
Per cent	58.6	45.2	29.3	19.2	13.4
Two days before cold					
Colds during week (N=11)	6	5	5	3	1
"Week-end colds" (N=15)	11	7	7	4	1
All colds (N=26)	17	12	12	7	2
Per cent	65.3	46.2	46.2	26.9	7.7

While these data show a tendency for a greater incidence of drops in grip strength during the two days prior to a cold, the differences are not statistically significant by the X^2 test.

Similar comparisons for the January-February data are shown in the following tabulations:

	.2 kg. or More	.4 kg. or More	.6 kg. or More	.8 kg. or More	1.0 kg. or More
Noncold (N=374)					
Number	142	100	67	46	23
Per cent	38.0	26.8	17.9	12.3	6.1
One day before cold (N=34)					
Number	12	8	7	3	3
Per cent	35.3	23.5	20.6	8.8	8.8
Two days before cold (N=35)					
Number	19	14	13	8	3
Per cent	54.1	40.0	37.1	22.9	8.6
One day after cold (N=28)					
Number	16	13	12	8	4
Per cent	57.1	46.4	42.9	28.5	14.3

For the data given above the X^2 test showed no significant differences between the percentages for all cases and for one day before the cold. The differences between all cases and two days before a cold were statistically significant at the 1 per cent level for drops of .6 or more and at the 6 per cent to 10 per cent level for the other categories. For one day after a cold, the differences were significant at the 1 per cent level for .6 kg. or more, and at the 2, 3, and 4

per cent levels respectively for drops of .8 kg. or more, .4 kg. or more, and .2 kg. or more.

The lower score made on either of the two days prior to the occurrence of a cold is compared with the lower scores of consecutive pairs of days for the noncold data for January-February in the following tabulation:

	.2 kg. or More	.4 kg. or More	.6 kg. or More	.8 kg. or More	1.0 kg. or More
Noncold paired (N=256)					
Number	154	112	71	47	23
Per cent	60.2	43.7	27.7	18.4	9.0
Two days before cold (N=31)					
Number	22	15	14	9	5
Per cent	70.0	48.4	45.1	29.0	16.1

In each instance the per cent of cases showing drops during the two days prior to a cold is greater than that for all cases paired, but these differences are statistically significant only for drops of .6 kg. or more. The X^2 test shows the difference here to be significant at the 5 per cent level.

The analyses in the foregoing tabulations do not take into consideration the positive deviations from the criterion scores. These were used with the negative deviations in computing the mean deviations from the criterion scores for each of the above classifications. The means and standard deviations of all deviations under each classification are shown below: The "t" test gives the significance of the difference between the means for each of the cold groups and the means for the comparable noncold data.

	Number	Mean	S.D.	"t"	Level of Significance
Noncold					
November-December	233	.055	.773		
January-February	256	.026	.686		
One day before cold					
November-December	29	—.130	.553	1.25	Not significant
January-February	34	.066	.664	.33	Not significant
Two days before cold					
November-December	26	.125	.802	.44	Not significant
January-February	35	—.275	.712	2.47	1 to 2 per cent
One day after cold					
November-December	22	—.101	.972	.88	Not significant
January-February	28	—.275	.863	2.20	3 per cent
Lower of noncold paired					
November-December	157	—.377	.634		
January-February	256	—.307	.562		
Lower of two days before cold					
November-December	26	—.414	.473	.28	Not significant
January-February	31	—.527	.601	2.04	4 per cent

From the above tabulation it is evident that there is a tendency for the means and standard deviations of the January-February noncold data to be lower than those for the November-December data. This would seem to indicate that the variability of the scores was slightly reduced by the use of the criterion score in the testing procedure. For the November-December data there are no significant differences between the noncold means and the cold means. For the January-February data, the cold means for two days before and one day after are significantly lower than the means for all cases with which they are compared.

Similar analyses were made of the breathing capacity data. The results of these analyses for the November-December data are shown below:

	Cubic Inches						
	1 or More	2 or More	3 or More	4 or More	5 or More	6 or More	7 or More*
Noncold (N=226)							
Number	89	65	41	30	24	14	7
Per cent	39.3	28.7	18.1	13.3	10.6	6.2	3.1
One day before cold							
Colds during week (N=14)	7	7	6	4	2	2	2
"Week-end colds" (N=15)	10	8	5	4	3	2	2
All colds (N=29)	17	15	11	8	5	4	4
Per cent	58.5	51.7	38.0	27.5	17.2	13.8	13.8
Two days before cold							
Colds during week (N=11)	5	3	2	1			
"Week-end colds" (N=15)	9	4	2				
All colds (N=26)	14	7	4	1			
Per cent	53.8	26.9	15.4	3.8			
One day after cold (N=22)							
Number	10	7	5	4	3	2	1
Per cent	45.4	31.8	22.7	18.3	13.6	11.0	4.5

* The average breathing capacity for these subjects was about 60 cubic inches. Thus, a drop of 1 cubic inch is approximately 1.7 per cent, 2 cubic inches 3.3 per cent, 3 cubic inches 5 per cent, etc.

It may be noted that there were more drops in breathing capacity occurring on the day before a cold than in the noncold data. The differences in percentages are significant by the X^2 test at the 1 per cent to 5 per cent levels of confidence for drops of 1, 2, 3, 4 or more cubic inches. There are no significant differences in the percentages of drops for the noncold data and two days before or one day after a cold.

As for the grip strength scores, the breathing capacity noncold scores were paired and the lower score selected from each pair. A

comparison of these scores with the lower score for either of the two days prior to a cold for the November-December data is shown below:

	Cubic Inches						
	1 or More	2 or More	3 or More	4 or More	5 or More	6 or More	7 or More
Noncold paired (N=154)							
Number	99	76	52	38	35	20	10
Per cent	64.3	49.4	33.1	24.7	22.8	13.0	6.5
Two days before cold							
Colds during week (N=11)	9	8	7	5	2	2	2
"Week-end colds" (N=15)	13	10	6	4	3	2	2
All colds (N=26)	22	18	13	9	5	4	4
Per cent	84.6	69.2	50.0	34.7	19.3	15.4	15.4

It is apparent from this tabulation that there were more drops in breathing capacity during the two days preceding a cold than occurred in the noncold data. These differences are statistically significant at the 5 per cent level for drops of 1 cubic inch or more and 2 cubic inches or more.

In the following tabulation it may be noted that for the January-February data there is a higher percentage of drops in breathing capacity for the days prior to and following a cold than in the noncold data. For one day before a cold the X^2 test shows the differences to be significant at the 2 per cent level for drops of 3 cubic inches or more, and at the 3 per cent level for drops of 4 cubic inches or more. For two days before a cold, the differences are significant at the 1 per cent level for drops of 2 cubic inches or more, 4 per cent for 4 cubic inches or more, 6 per cent for 1 cubic inch or more, and 8 per cent for 3 cubic inches or more. For the first day after a cold the differences are not significant, the highest level of confidence indicated being 6 per cent for drops of 3 cubic inches or more.

	Cubic Inches				
	1 or More	2 or More	3 or More	4 or More	5 or More
Noncold (N=395)					
Number	139	81	49	36	20
Per cent	35.1	20.5	12.4	10.9	5.1
One day before cold (N=34)					
Number	17	10	9	7	4
Per cent	50.0	29.4	26.5	20.6	11.8
Two days before cold (N=35)					
Number	18	14	8	7	1
Per cent	51.5	40.0	22.9	20.0	2.9
One day after cold (N=28)					
Number	12	9	7	5	4
Per cent	43.3	32.1	25.0	17.7	14.3

From the following tabulation of the January-February data it is again evident that more drops in breathing capacity occurred in the two days before a cold than in the noncold data when the lower of paired scores were used as the basis of comparison. These differences are significant at the 2 per cent to 4 per cent level of confidence for drops of 4 cubic inches or more, 3 cubic inches or more, 2 cubic inches or more, or 1 cubic inch or more.

	Cubic Inches						
	1 or More	2 or More	3 or More	4 or More	5 or More	6 or More	7 or More
Noncold paired (N=273)							
Number	159	103	65	48	26	17	12
Per cent	58.2	37.7	23.8	17.6	9.5	6.2	4.4
Two days before cold (N=31)							
Number	24	18	13	11	3	3	2
Per cent	77.3	58.1	41.9	35.5	9.7	9.7	6.5

The means of all deviations, both positive and negative, from the criterion scores for breathing capacity, are shown below. The "t" values indicate the significance of the differences between the means for the cold data and the comparable body of noncold data.

	Number	Mean	S.D.	"t"	Level of Significance
All Cases					
November-December	226	.259	3.794		
January-February	395	.497	3.378		
One day before cold					
November-December	29	—1.629	4.101	2.49	1 to 2 per cent
January-February	34	— .544	3.930	1.70	5 to 10 per cent
Two days before cold					
November-December	26	— .827	2.976	1.40	10 to 20 per cent
January-February	35	— .450	3.487	1.58	10 to 20 per cent
One day after cold					
November-December	22	.932	4.905	.77	Not significant
January-February	28	.070	4.277	.63	Not significant
Lowest of paired cases					
November-December	154	—1.841	3.275		
January-February	273	—1.389	2.650		
Lowest of two days before cold					
November-December	26	—3.058	3.082	1.77	5 to 10 per cent
January-February	31	—2.508	2.650	2.23	1 to 2 per cent

The preceding tabulation shows that the mean score for breathing capacity either one or two days prior to the occurrence of a cold tends to be lower than the mean breathing capacity scores obtained from the noncold data. These differences are fairly small in terms of cubic inches but they are statistically significant in most instances.

From the analyses given in tabulations, pages 188 to 193, it may be concluded that for preschool children there appears to be some relationship between daily scores made in grip strength and breathing capacity and the occurrence of colds. The next step in the investigation is to determine whether or not this relationship is close enough to have any predictive value in terms of individual children.

Since both breathing capacity and grip strength showed some relationship to the incidence of colds, it was thought that a combined criterion using both measures might be useful in determining when a cold was about to occur. The use of a combined criterion would also serve to eliminate many of the chance fluctuations in either of the scores taken separately. The following criteria were tried:

1. A drop of 2 cubic inches in breathing capacity and a drop of .2 kg. in grip strength occurring on the same day or on consecutive days.
2. A drop of 2 cubic inches in breathing capacity and a drop of .5 kg. in grip strength occurring on the same day or on consecutive days.

A second set of criteria were also developed which were based on simultaneous drops in both scores or a marked drop in the score of either test.

3. Drops of 2 cubic inches in breathing capacity and .5 kg. in grip strength occurring on the same day or consecutive days, *OR* a drop of 4 cubic inches in breathing capacity, *OR* a drop of .6 kg. in grip strength.
4. As in 3, above, except that .7 kg. in grip strength was used.
5. As in 3, above, except that .9 kg. in grip strength was used.
6. Drops of 3 cubic inches in breathing capacity and .7 kg. in grip strength occurring on the same day or consecutive days, *OR* 5 cubic inches in breathing capacity, *OR* 1.00 kg. in grip strength.

For each criterion the data for each child were examined and the number of times the criterion was equaled or exceeded was recorded. If a cold occurred within two days after the criterion combination was noted, the cold was considered to have been "predicted" by the drops in scores of the two tests. Colds which occurred independently of the criterion being used were considered as having been "not predicted." The success in "predicting" colds by each set of

criterion scores is shown below. The number of possible predictions was 223 in the November-December data and 368 in the January-February data.

	Cold Occurred*		No Cold Occurred	
	Cold Predicted	No Cold Predicted	Cold Predicted	No Cold Predicted
	Criterion 1			
November-December	18	9	34	162
January-February	17	16	53	282
	Criterion 2			
November-December	14	13	24	174
January-February	13	20	38	297
	Criterion 3			
November-December	25	2	51	145
January-February	30	7	79	252
	Criterion 4			
November-December	25	2	49	147
January-February	29	8	80	251
	Criterion 5			
November-December	22	5	43	153
January-February	26	11	71	260
	Criterion 6			
January-February	23	14	48	279

* The total of colds is not the same for all criteria because no data were available for the week-ends. Thus colds occurring on Tuesday or Sunday could be used only if the criteria were fulfilled by the scores made on Monday or on Friday since two consecutive days' scores were not available.

The degree of success with which each criterion predicts colds may be more easily determined if the figures given in the preceding tabulation are reduced to the per cent of cases meeting the criterion and developing colds within the following two days and the per cent of cases not meeting the criterion which develop colds. These percentages are shown below.

Criterion	Per Cent of Cases Meeting Criterion Which Develop Colds		Per Cent of Cases Not Meeting Criterion Which Develop Colds	
	November-December	January-February	November-December	January-February
1	34.7	24.3	5.3	5.4
2	38.9	25.6	7.0	6.3
3	32.7	27.5	1.4	2.7
4	33.8	26.6	1.4	3.2
5	33.9	26.9	3.2	4.6
6		22.6		7.6

The comparison of percentages given above provides two estimates of the efficiency of the various criteria in predicting the occurrence of colds. The first is a measure of success: Of the colds predicted,

how many actually occur? From the first two columns of the preceding tabulation it may be seen that the success of the criteria varies, but that all indicate that the investigator using them could expect to be correct in his cold predictions about one-third of the time. The second is a measure of failure: How often will a cold occur which has not been predicted by the criterion? From the last two columns it will be seen that only a very small per cent of the cases which do not meet these criteria develop colds.

The X^2 test was applied to the data from the tabulation above. For each of the criteria the results differed significantly (at the 1 per cent level of confidence) from those which would be expected by chance alone.

A further estimate of the degree of relationship between the prediction of colds by these criteria and the occurrence of colds was made by computing the tetrachoric correlations from the data used in the X^2 tables. These are shown below:

Criterion	Tetrachoric Correlation	
	November-December	January-February
1	.62	.56
2	.60	.54
3	.80	.69
4	.81	.69
5	.75	.58
6		.39

From these correlations it would seem that the best predictions would be obtained with criterion 3 or criterion 4. From the above tabulation it may be seen that predictions on the basis of these criteria miss only about 15 per cent of all the colds which occur. It must also be pointed out, however, that these criteria will predict three colds for every one which actually does occur, being successful only about one-third of the time.

To be able to state that a child will have a cold two days before any symptoms are visible and to be correct one-third of the time may not seem a very significant accomplishment to the adult who usually knows when he is "getting a cold." But to do it with a test which takes less than a minute to administer, for four-year-old children who are not yet aware of the symptoms which precede a cold, suggest that these tests may have possibilities for use in the practical school situation. The fact that the prediction is fulfilled only one-third of the time must also be considered in the light of the fact that an adult may "feel a cold coming on" one day and

find that the symptoms have disappeared the following day after a night's rest.

It is not the purpose of this paper to suggest that the tests actually measure the presence of an infection of the upper respiratory tract. It is more likely that they measure a general fatigued condition. When such a condition is present, the child is probably more susceptible to infection. Since the present investigation was made during a time when colds and influenza were prevalent in the community, it may well be that the percentage of children developing colds following fatigue was much greater than it would be during a different period of the year.

From the present study it does not seem defensible to draw any very definite conclusions as to the usefulness of the tests of breathing capacity and grip strength in predicting colds in all situations. The findings do suggest, however, that the tests merit further investigation under a wider range of conditions.

It is suggested that the tests should be tried out in some institutional situation where the environmental conditions are relatively stable for all children and where the tests could be administered seven days a week. In such a situation the investigator could personally record the occurrence of colds for each child and thus be free from dependence upon reports of parents as to when a cold existed, when it started, its nature, and the possible sources of exposure.

If further investigations confirm the results of the present study it is suggested that the tests might have a practical usefulness in school and institutional situations. To test all children every day throughout the school year would probably be unnecessary. But if the tests were used during times of influenza or cold epidemics, it might be possible to reduce the amount of illness among the children tested. If a child's test scores were low for a given day, the parents or adults in charge of the child might be informed and additional rest and other precautionary measures suggested for a day or two. What the result of such a procedure would be in reducing the incidence of colds among children can be determined only by investigation.

REFERENCES

1. Abernethy, Ethel Mae: Relationships between mental and physical growth. Washington, D. C., National Research Council, 1936. Pp. vii, 80. (Monographs of Society for Research in Child Development, Vol. I, No. 7.)
2. Affleck, G. B.: A minimum set of tentative physical standards for children of school age. Ped. Sem., 1920, 27, 324-353.
3. Alden, Florence D. and Top, Hilda: Experiment on the relation of posture to weight, vital capacity and intelligence. Res. Quart., Amer. Physical Educ. Assoc., 1931, 2, 38-41.
4. Anderson, Harold H. and Smith, Ruth Sloan: Motivation of young children: The constancy of certain behavior patterns. J. Exper. Educ., 1933-1934, 2, 138-160.
5. Anderson, Theresa W.: Weighted strength tests for the prediction of athletic ability in high school girls. Res. Quart., Amer. Physical Educ. Assoc., 1936, 7, 136-142.
6. Anderson, Theresa W.: Studies in strength testing for high school girls. Res. Quart., Amer. Physical Educ. Assoc., 1937, 8, 69-73.
7. Apperly, Frank L.: Variations in pulmonary vital capacity in health: Daily, seasonal, and at moderate altitudes. Proc. Soc. Exper. Biol. and Med., 1939, 40, 294-298.
8. Arnett, John H.: Vital capacity of the lungs: Changes occurring in health and disease. J. Clin. Investigation, 1935, 14, 543-549.
9. Arnett, John H. and De Orsay, Ralph H.: The variability of the vital capacity of the lungs in youth. Amer. J. Med. Sci., 1937, 193, 684-687.
10. Arnett, John H. and Kornblum, K.: Vital capacity: An inquiry into its value as a diagnostic procedure. Annals Clin. Med., 1924, 3, 255-274.
11. Arthur, William: On the relationship between strength of grip and certain mental and sensory characters. Biometrika, 1924, 16, 299-327.
12. Bagley, William Chandler: On the correlation of mental and motor ability in school children. Amer. J. Psychol., 1900-1901, 12, 193-205.
13. Baldwin, Bird T.: Physical growth and school progress: A study in experimental education. U. S. Bureau of Educ., Bull., No. 10. Washington: Government Printing Office, 1914. Pp. 215.
14. Baldwin, Bird T.: The physical growth of children from birth to maturity. Univ. Iowa Stud., Stud. in Child Welfare, 1921, 1, No. 1, Pp. 411.
15. Baldwin, Bird T.: Anthropometric measurements. [In] Terman, Lewis M.: Genetic studies of genius. Vol. I. Mental and physical traits of a thousand gifted children. Stanford, California: Stanford University Press, 1925. Pp. xv, 648. (Chapter VII, p. 135-171)
16. Baldwin, Bird T.: Breathing capacity according to height and age of

American-born boys and girls of school age. Amer. J. Physical Anthropol., 1928, 12, 257-267.

17. Benedict, Francis G. and Talbot, Fritz B.: Metabolism and growth from birth to puberty. Carnegie Institute Washington, 1921, No. 302, Pp. vi, 213.
18. Berry, Richard A. and Porteus, S. D.: Intelligence and social valuation: A practical method for the diagnosis of mental deficiency and other forms of social inefficiency. Department of Research, Publication of the Training School at Vineland, New Jersey, 1920, No. 20, Pp. 100.
19. Beyer, Henry G.: The influence of exercise on growth. Amer. Physical Educ. Rev., 1896, 1, 76-87.
20. Binet, Alfred and Vaschide, N.: Memoirs originaux (I. La psychologie a l'école primaire, p. 1-14; II. Expériences de force musculaire et de fond chez les jeunes garçons, p. 15-63; III. Épreuves de vitesse chez les jeunes garçons, p. 64-98; IV. Expériences sur la respiration et la circulation du sang chez les jeunes garçons, p. 99-132; VI. Échelle des indications données par les différents tests, p. 137-141; VII. Corrélation des épreuves physiques, p. 142-172; VIII. La mesure de la force musculaire chez les jeunes gens. La force de pression de la main, la traction, la corde lisse, le saut, p. 173-199; IX. Expériences de vitesse chez les jeunes gens, p. 200-224; X. Données anatomiques, capacité vitale et vitesse du coeur chez 40 jeunes gens, p. 225-232; XI. Échelle des indications données par les tests, p. 233-235; XII. Corrélation des tests de force physique, p. 236-244; XIII. Critique du dynamomètre ordinaire, p. 245-252.) L'Année Psychologique, 1897, 4, Part I, 1-252.
21. Blackhurst, Dorothy Jean: The value of play apparatus in developing motor control in preschool children. Unpublished master's thesis, University of Iowa, 1927. Pp. 77.
22. Bovard, John F. and Cozens, Frederick W.: Tests and measurements in physical education, 1861-1925: A treatment of the original sources with critical comment. University Oregon Publications, Physical Educ. Series, Vol. I, No. 1, 1926. Pp. 94.
23. Bowen, W. P.: The spirometer as a scientific instrument. Amer. Physical Educ. Rev., 1906, 11, 141-148.
24. Boynton, Bernice: The physical growth of girls: A study of the rhythm of physical growth from anthropometric measurements on girls between birth and eighteen years. Univ. Iowa Stud., Stud. in Child Welfare, 1936, 12, No. 4, Pp. 105.
25. Carman, Ada: Pain and strength measurements of 1507 school children in Saginaw, Michigan. Amer. J. Psychol., 1899, 10, 392-398.
26. Chamberlain, Carl G. and Smiley, Dean F.: Functional health and the physical fitness index. Res. Quart., Amer. Physical Educ. Assoc., 1931, 2, 193-198.
27. Chase, Lucile: Motivation of young children: An experimental study of the influence of certain types of external incentives upon the performance of a task. Univ. Iowa Stud., Stud. in Child Welfare, 1932, 5, No. 3, Pp. 119.

28. Christopher, W. S.: Report on child study and scientific pedagogy. [In] Forty-fifth annual report of the Board of education for the year ending June 23, 1899, Public Schools of the City of Chicago, 1900. Chicago: Public Schools, 1900. Pp. 245. (Pp. 27-75)
29. Collins, Selwyn D. and Clark, Taliaferro: Physical measurements of boys and girls of native white race stock (third generation native born) in the United States. Physical Measurement Studies, No. I. U. S. Public Health Service Reports, 1929, 44, No. 18, 1059-1083.
30. Cripps, Lucy D., Greenwood, Major, and Newbold, Ethel M.: A biometric study of the interrelation of "vital capacity," stature, stem length and weight in a sample of healthy male adults. Biometrika, 1922-1923, 14, 316-336.
31. Cureton, Thomas Kirk: Analysis of vital capacity as a test of condition for high school boys. Res. Quart., Amer. Physical Educ. Assoc., 1936, 7, 80-92.
32. De Busk, B. W.: Height, weight, vital capacity and retardation. Ped. Sem., 1913, 20, 89-92.
33. De Busk, Burchard W.: The vital index in development. Ped. Sem., 1917, 24, 1-18.
34. Deming, Jean and Hanner, James P.: Respiration in infancy. II. A study of rate, volume, and character of respiration in healthy infants during the neonatal period. Amer. J. Dis. Child., 1936, 51, 823-831.
35. Deming, Jean and Washburn, Alfred H.: Respiration in infancy. I. A method of studying rates, volume, and character of respiration with preliminary report of results. Amer. J. Dis. Child., 1935, 49, 108-124.
36. Dewey, Evelyn, Child, Emily, and Ruml, Beardsley: Methods and results of testing school children; manual of tests used by the Psychological Survey in the Public Schools of New York City, including social and physical studies of the children tested. New York: E. P. Dutton, 1920. Pp. ix, 176.
37. Dimock, Hedley S.: Rediscovering the adolescent: A study of personality development in adolescent boys. New York: Association Press, 1937. Pp. xx, 287.
38. Dreyer, Georges and Hanson, George Fulford: The assessment of physical fitness by correlation of vital capacity and certain measurements of the body. New York: Paul B. Hoeber, 1921. Pp. xiv, 127.
39. DuBois, Delafield, and DuBois, Eugene F.: Clinical calorimetry. X. A formula to estimate the approximate surface area if height and weight be known. Arch. Internal Med., 1916, 17, 863-871.
40. Edwards, D. J. and Wilson, May G.: An analysis of some of the factors of variability in the vital capacity measurements of children. Arch. Internal Med., 1922, 30, 638-647.
41. Edwards, Dayton J. and Wilson, May G.: The standard for comparing the vital capacity of subjects of different size and a chart for practical use. J. Lab. & Clin. Med., 1939, 24, 543-546.
42. Emerson, Paul W. and Green, Hyman: Vital capacity of the lungs of children. Amer. J. Dis. Child., 1921, 22, 202-211.

43. Flagstad, A. E. and Kollman, Sara: Vital capacity and muscle study in 100 cases of scoliosis. J. Bone & Joint Surgery, 1928, 10, 724-734.
44. Franzen, Raymond: Physical measures of growth and nutrition. (School Health Research Monograph, No. II) New York: American Child Health Association, 1929. Pp. xii, 138.
45. Friedman, Eli and Howes, John B. Jr.: Is the vital capacity an aid in the diagnosis of hilum gland tuberculosis? J. Amer. Med. Assoc., 1929, 92, 363.
46. Garrett, Henry E. and Schneck, Matthew R.: Psychological tests, methods, and results. New York: Harper and Brothers, 1933. Pp. x, 235. (Part II, p. 87-91)
47. Garrison, S. C. and Pullias, G. M.: Bright children (mental and physical correlations). Psychol. Clin., 1922-1923, 14, 259-263.
48. Gates, Arthur I.: The nature and educational significance of physical status and of mental, physiological, social and emotional maturity. J. Educ. Psychol., 1924, 15, 329-358.
49. Gilbert, J. Allen: Researches on the mental and physical development of school children. Stud. Yale Psychol. Lab., 1894, 2, 40-100.
50. Gilbert, J. Allen: Researches upon school children and college students. Univ. Iowa Stud., Stud. in Psychol., 1897, 1, 1-39.
51. Gittings, Ina E.: Correlation of mental and physical traits in University of Arizona freshman women. Amer. Physical Educ. Rev., 1927, 32, 569-583.
52. Gould, Harley N. and Lockhart, Alice: The physique of women students at Newcomb College of Tulane University. II. Vital capacity. Res. Quart., Amer. Physical Educ. Assoc., 1930, 1, No. 4, 36-45.
53. Griffith, Fred R., Pucher, George W., Brownell, Katherine A., Klein, Jennie D., and Carmer, Mable E.: Studies in human physiology. IV. Vital capacity, respiratory rate and volume, and composition of expired air. Amer. J. Physiol., 1929, 89, 555-583.
54. Griffitts, C. H.: The inadequacy of strength norms. Res. Quart., Amer. Physical Educ. Assoc., 1935, 6, 117-124.
55. Hansson, K. G.: Vital capacity in trunk deformities. Res. Quart., Amer. Physical Educ. Assoc., 1939, 10, 72-77.
56. Harris, Jane E.: The differential measurement of force and velocity for junior high school girls. Res. Quart., Amer. Physical Educ. Assoc., 1937, 8, 114-121.
57. Hastings, William W.: A manual for physical measurements for use in normal schools, public and preparatory schools, boys' clubs, girls' clubs, and Young Men's Christian Associations, with anthropometric tables for each height of each age and sex from five to twenty years, and vitality coefficients. Springfield, Mass.: The International Young Men's Christian Association Training School, 1902. Pp. xviii, 112.
58. Heinlein, Julia Heil: A study of dextrality in children. Ped. Sem. & J. Genet. Psychol., 1929, 36, 91-119.
59. Hernlund, V. F.: The selection of physical tests for measuring Y.M.C.A. secretaries. Res. Quart., Amer. Physical Educ. Assoc., 1935, 6 (Supplement), 26-36. (March)

60. Hinckley, Robert G.: Vital capacity determinations in health examinations. J. -Lancet, 1937, 57, 478-481.
61. Hoefer, Carolyn and Hardy, Mattie Crumpton: The influence of improvement and physical condition on intelligence and educational achievement. [In] Twenty-Seventh Yearbook, National Society for Study of Education. Nature and Nurture. Part I: Their Influence Upon Intelligence. Bloomington, Ill.: Public School Publishing Co., 1928. Pp. ix, 465. (p. 371-387)
62. Hollingworth, Leta S. and Taylor, Grace A.: B. Studies of physical condition and growth: B2. Size and strength of children who test above 135 IQ. [In] Twenty-Third Yearbook of the National Society for Study of Education, Part I: The Education of Gifted Children. Bloomington, Ill.: Public School Publishing Co., 1924, Pp. 443. (p. 221-237)
63. Holzinger, Karl J.: Note on the relation of vital capacity to certain psychical characters. Biometrika, 1924, 16, 139-156.
64. Hutchinson, John: The spirometer, the stethoscope, and scale-balance; their use in discriminating diseases of the chest, and their value in life offices; with remarks on the selection of lives for assurance companies. London: John Churchill, Princes Street, Soho, 1852, Pp. 79.
65. Jackson, C. M.: Physical measurements of the female students at the University of Minnesota, with special reference to body build and vital capacity. Amer. J. Physical Anthropol., 1928-1929, 12, 363-413.
66. Jackson, C. M. and Lees, H. D.: The correlations between vital capacity and various physical measurements in 100 healthy male university students. Amer. J. Physiol., 1929, 87, 654-666.
67. Jersild, Arthur T., and others: Training and growth in the development of children: A study of the relative influence of learning and maturation. Teach. Coll., Columbia Univ., Child Develop. Monog., 1932, No. 10, Pp. ix, 73.
68. Johnson, Buford: Mental growth of children in relation to rate of growth in bodily development: A report of the Bureau of Educational Experiments, New York City. New York: E. P. Dutton, [c. 1925] Pp. xix, 160.
69. Jones, D. Caradog: A statistical study of the relationship between mental or athletic activity and physical or respiratory development. Science Progress, 1926-1927, 21, 260-269.
70. Kelly, Helen Garside: A study of individual differences in breathing capacity in relation to some physical characteristics. Univ. Iowa Stud., Stud. in Child Welfare, 1933, 7, No. 5, Pp. 59.
71. Kiefer, Frieda A.: Manual motor correlation in superior children. J. Appl. Psychol., 1929, 13, 357-371.
72. Knott, Virginia B.: Physical measurement of small children: A study of anthropometric reliabilities for children three to six years of age. Unpublished doctor's thesis, State University of Iowa, 1938. Pp. 145 ms.
73. Kohs, Samuel C.: The progressive error of the Smedley dynamometer. J. Exper. Psychol., 1917, 2, 304-312.

74. Lemon, Willis S.: Historic review of American and English literature on vital capacity. Minnesota Med., 1931, 14, 1031-1041.
75. Lemon, Willis S. and Moersch, Herman J.: Comparison of constants for the determination of vital capacity. Arch. Internal Med., 1924, 33, 118-127.
76. Louttit, C. M. and Halford, J. F.: The relation between chest girth and vital capacity. Res. Quart., Amer. Physical Educ. Assoc., 1930, 1, 34-35.
77. McCloy, C. H.: On using the spirometer as an instrument of precision. Amer. Physical Educ. Rev., 1927, 32, 321-327.
78. McCloy, Charles H.: Appraising physical status: The selection of measurements. Univ. Iowa Stud., Stud. in Child Welfare, 1936, 12, No. 2, Pp. 126.
79. McCloy, C. H.: Appraising physical status: methods and norms. Univ. Iowa Stud., Stud. in Child Welfare, 1938, 15, No. 2, Pp. 260.
80. McCloy, Charles Harold: Tests and measurements in health and physical education. New York: F. S. Crofts, 1939. Pp. xx, 392.
81. MacCurdy, Howard Leigh: A test for measuring the physical capacity of secondary school boys. New York: Published by Author, 1933. Pp. v, 59.
82. MacDonald, Arthur: Experimental study of children, including anthropometrical and psycho-physical measurements of Washington School children. [In] Report of the Commissioner of Education for the year 1897-1898. Washington, D. C.: Government Printing Office, 1899, U. S. Bur. Educ., 1897-1898. Vol. 1, Part I, Pp. 1280. (p. 985-1204)
83. MacDonald, Arthur: Mentality and anthropometrical tests. Medical Times, November, 1925, 3-8.
84. MacKinnon, D. C. and Jackson, C. M.: Changes in the physical measurements of male students at the University of Minnesota during the last thirty years. Amer. J. Anat., 1931, 47, 405-423.
85. McKinstry, Helen: Evaluation of qualities and capacities essential to teaching success. Res. Quart., Amer. Physical Educ. Assoc., 1933, 4, 5-25.
86. Mead, Cyrus D.: The relations of general intelligence to certain mental and physical traits. Teach. Coll., Columbia Univ., Cont. to Educ., 1916, No. 76, Pp. 117.
87. Meredith, Howard V.: The rhythm of physical growth: A study of eighteen anthropometric measurements on Iowa City white males ranging in age between birth and eighteen years. Univ. Iowa Stud., Stud. in Child Welfare, 1935, 11, No. 3, Pp. 128.
88. Moersch, Herman J.: The vital capacities of one thousand surgical patients. Arch. Internal Med., 1926, 37, 128-143.
89. Monahan, Jane E. and Hollingworth, Leta S.: Neuro-muscular capacity of children who test above 135 IQ (Stanford-Binet). J. Educ. Psychol., 1927, 18, 88-96.
90. Myers, J. A.: Vital capacity of the lungs: A handbook for clinicians and others interested in the examination of the heart and lungs both in health and disease. Baltimore: Williams & Wilkins, 1925. Pp. 140.

91. Newcomer, Mabel: Physical development of Vassar College students, 1884-1920. Quart. Publication Amer. Statistical Assoc., 1920-21, 17, 976-982.
92. Parsons, Clifford G. and Wright, F. Howell: Circulatory function in the anemias of children. I. Effect of anemia on exercise tolerance and vital capacity. Amer. J. Dis. Child., 1939, 57, 15-28.
93. Pasmore, Edith E. and Weymouth, Frank W.: The relation of vital capacity to other physical measurements in women. Amer. Physical Educ. Rev., 1924, 29, 166-175.
94. Patrick, James R. and Rowles, Emmett: Intercorrelations among metabolic rate, vital capacity, blood pressure, intelligence, scholarship, personality, and other measures on university women. J. Appl. Psychol., 1933, 17, 507-521.
95. Peabody, F. W. and Wentworth, J. A.: Clinical studies of the respiration: IV. The vital capacity of the lungs and its relation to dyspnea. Arch. Internal Med., 1917, 20, 443-467.
96. Porter, W. Townsend: The growth of St. Louis children. Trans. Acad. of Science of St. Louis, 1892-1894, 6, 263-380. [46 charts additional]
97. Pratt, Joseph H.: Long-continued observations on the vital capacity in health and heart disease. Amer. J. Medical Sci., 1922, 164, 819-832.
98. Prudential Insurance Company of America: Determining circulatory fitness: Flarimeter tests. Newark, N. J.: Prudential Insurance Co. of America, 1931. Pp. 31.
99. Pyle, William Henry: The examination of school children: A manual of directions and norms. New York: Macmillan, 1913. Pp. v, 70.
100. Reed, William T.: Physical ability tests for boys. Amer. Physical Educ. Rev., 1926, 31, 902-903.
101. Roberts, F. L.: Vital capacity of children infected with hookworm. Amer. J. Public Health, 1925, 15, 774-780.
102. Roberts, Frank L. and Crabtree, James A.: The vital capacity of the negro child. J. Amer. Med. Assoc., 1927, 88, 1950-1952.
103. Rogers, Frederick Rand: Tests and measurement programs in the redirection of physical education. New York: Teach. Coll., Columbia Univ., School Administration Series, 1927, Pp. xix, 166.
104. Rogers, Frederick Rand: Physical capacity tests. Notes on testing techniques and the significance of tests. New York: A. S. Barnes and Co., 1931. Pp. viii, 53.
105. Rogers, Frederick Rand: The significance of strength tests in revealing physical condition. Res. Quart., Amer. Physical Educ. Assoc., 1934, 5, 43-46.
106. Schwarz, Louis, Britten, Rollo H., and Thompson, Lewis R.: Studies in physical development and posture. I. The effect of exercise on the physical condition and development of adolescent boys; II. Bodily growth with age; III. Physical fitness as reflected in tests of muscular strength. Public Health Bulletin, No. 179. Washington, D. C.: Treasury Department, U. S. Public Health Service, 1928. Pp. xii, 124.
107. Shaffer, G. Wilson: Alertness and motor abilities of athletes and non-athletes. Mental Meas. Monog., 1931, 8, 1-65.

108. Smedley, Fred W.: Report of director of department of child-study and pedagogic investigation. [In] Forty-Sixth Annual Report of the Board of Education. Public Schools of the City of Chicago, 1900. Pp. 280. (p. 47-116)
109. Stalnaker, Elizabeth M.: A comparison of certain mental and physical measurements of school children and college students. J. Comp. Psychol., 1923, 3, 181-239; 431-468.
110. Stewart, Chester A.: The vital capacity of the lungs of children in health and disease. Amer. J. Dis. Child., 1922, 24, 451-496.
111. Stewart, Chester A.: A consideration of the extent of the normal variability of the vital capacity of the lungs of children. Amer. Rev. Tuberculosis, 1926, 13, 272-277.
112. Stewart, Chester A.: The vital capacity of the lungs of children having masked juvenile tuberculosis. Amer. Rev. Tuberculosis, 1926, 13, 278-283.
113. Stewart, Chester A. and Sheets, O. B.: The value of the determination of the vital capacity of the lungs in the diagnosis and prognosis of pulmonary tuberculosis in children. J. -Lancet, 1922, 42, 253-257.
114. Stiles, C. W. and Graves, Floyd: Lung capacity of children. Spirometer tests of 1,618 white school children (751 boys, 867 girls) in the City of X. U. S. Public Health Reports, 1915, 30, 3067-3072.
115. Strong, Edward K. Jr.: The effect of various types of suggestion upon muscular activity. Psychol. Rev., 1910, 17, 279-293.
116. Thomas, Henry M., Jr.: The present status of vital capacity as a test of pulmonary efficiency. Medical Clinics of North America, 1935, 18, 1685-1695.
117. Turner, Abby H.: The vital capacity of college women. Amer. Physical Educ. Rev., 1927, 32, 593-606.
118. Turner, Abby H.: Vital capacity in college women. I. Standards for normal vital capacity in college women. Arch. Internal Med., 1930, 46, 930-937.
119. Turner, Abby H.: Vital capacity in college women. II. A study of students with high and low vital capacity. Arch. Internal Med., 1930, 46, 938-945.
120. Van Dalen, Deobald: The contribution of breathing capacity to the physical fitness index. Res. Quart., Amer. Physical Educ. Assoc., 1936, 7, 93-95.
121. Wallin, J. E. Wallace: Experimental study of mental defectives. Educational Psychol. Monog., No. 7, Baltimore: Warwick and York, 1912. Pp. vi, 155.
122. Wallin, John E. Wallace: Clinical and abnormal psychology. A textbook for educators, psychologists, and mental hygiene workers. Boston: Houghton Mifflin, [c. 1927] Pp. xxii, 649.
123. Wells, Philip V.: Flarimeter tests of circulatory fitness. Res. Quart., Amer. Physical Educ. Assoc., 1934, 5, 44-48.
124. West, Howard F.: Clinical studies on the respiration: VI. A comparison of various standards for the normal vital capacity of the lungs. Arch. Internal Med., 1920, 25, 306-316.

125. Whipple, Guy Montrose: Manual of mental and physical tests; a book of directions compiled with special reference to the experimental study of school children in the laboratory or classroom. Baltimore: Warwick and York, 1910. Pp. xix, 534.

126. Wilson, May G. and Edwards, Dayton J.: The vital capacity of the lungs and its relation to exercise tolerance in children with heart disease: standards for normal vital capacity for children. The lung capacity in certain intrathoracic conditions. Amer. J. Dis. Child., 1921, 22, 443-454.

127. Wilson, May G. and Edwards, Dayton J.: Diagnostic value of determining vital capacity of lungs of children. J. Amer. Medical Assoc., 1922, 78, 1107-1110.

128. Wilson, May G., Edwards, D. J., and Liss, I. E.: Vital capacity as an aid in diagnosis of tracheobronchial adenopathy in children from 5 to 12 years of age; its significance in evaluation of vital capacity measurement of average normal children. Amer. J. Dis. Child., 1924, 27, 49-59.

129. Wissler, Clark: The correlation of mental and physical tests. Psychol. Rev., Monog. Suppl., 1901, 3, No. 6, 1-62.

130. Woo, T. L. and Pearson, Karl: Dextrality and sinistrality of hand and eye. Biometrika, 1927, 19, 165-199.

131. Young, Josephine E.: Hygiene of the school age. [In] Abt, Isaac A. [ed.]: Pediatrics. Vol. 1. Philadelphia: W. B. Saunders Co., 1923, Pp. xi, 1240. (Chapter VIII, p. 860-1131)

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